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THE REACTION OF WHEAT VARIETIES TO WHEAT STEM SAWFLY ATTACK[1]

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The wheat stem sawfly (*Cephus cinctus* Nort.) is a major limiting factor in the production of wheat in many areas of the Prairie Provinces. The loss has been estimated by Farstad (unpublished) at approximately 20 million bushels annually. This sawfly is a native of the mixed grass prairies where it infested various grasses chiefly *Agropyron* species. It was first reported attacking wheat in Canada at Souris, Manitoba, by Fletcher in 1895 (10). Since that time it has increased steadily in economic importance.

The region where this insect is causing or is likely to cause important economic losses is shown in Figure 1. It will be noted that this area coincides closely with the brown and dark brown soil zones of Alberta and Saskatchewan. These are the major wheat producing areas in these provinces and, incidentally, the areas in which the highest quality wheat is produced. Damage outside this area (in the black soil zone) occurs from time to time, but the economic hazard is slight because the pest can usually be controlled by the crop rotations in common use there.

LITERATURE

Criddle (5, 6) and Seamans (19) have outlined the life history and habits of the sawfly. The adult emerges from early June until mid-July. The date of first emergence and the length of flight depend on weather conditions. Eggs are deposited inside the developing wheat stem. Stems that have reached the "boot" stage are favoured for oviposition but stems at an earlier or later stage may also be infested. The young larva feeds on the inside of the stem, probably on the food materials being transported in the vascular tissue. As the plant reaches maturity the larva migrates to the base of the stem, where it girdles the culm at ground level causing the stem to break easily and fall to the ground. Such stems are difficult to retrieve with modern harvesting equipment and constitute the chief loss from the activities of this insect. The larva overwinters in the stub and pupates during the spring just before emergence as an adult.

In addition to the damage described above, Seamans *et al.* (20) has shown that substantial losses in yield and quality of grain are sustained as a result of the tunnelling and feeding of the larvae inside the culms. This type of damage has not been taken into consideration in evaluating varietal

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resistance by the investigators whose work is reviewed herein or by the authors in the present study. In all cases damage refers only to the breakage of stems as a result of sawfly activity. The reason for this is that the damage described by Seamans *et al.* (20) is difficult to evaluate and, in all probability, a close correlation exists between resistance to tunnelling and feeding and resistance to stem cutting. Furthermore should a variety resistant to stem cutting become established in a district the sawfly population would be greatly reduced and damage from tunnelling and feeding would become of minor importance.

Throughout this paper the term *vulgare* is used to refer to all varieties of the species *Triticum vulgare* Host. and the term *durum* to all varieties of the species *T. durum* Desf.

Evidence of differences in sawfly damage among wheat varieties has been reported by Ainslie (1), Criddle (5, 6) and Scegolev (18). The literature on insect resistance in crops plants has recently been reviewed by Snelling (21) and Platt and Farstad (15) and the Imperial Bureau of Plant Breeding and Genetics has issued a bibliography on insect pest resistance in plants (2).

A co-operative project between the Dominion Experimental Station, Swift Current, and the Dominion Entomological Laboratory, Lethbridge, was initiated to study sawfly resistance in wheat varieties. Results from this project were reported by Kemp (12) in 1934. He found that solid-stemmed varieties were cut by the sawfly less frequently than hollow-stemmed ones. Among the solid-stemmed types were certain vulgare varieties that Kemp imported from New Zealand, but which originally came from the Mediterranean region. Farstad (8) reported in 1940 that these solid-stemmed wheats were more resistant to cutting, that there was a higher larval mortality in such varieties, and that the fecundity of the adult tended to be reduced.

Platt (14) studied the effect of environmental factors on the solid-stem character. It was found that in solid-stemmed vulgare varieties the amount of solidness was greatest under long hours of sunshine and low rainfall and least under conditions of reduced sunshine and high rainfall. Continuous shading resulted in completely hollow culms. The solid-stemmed durum variety Golden Ball retained its solidness under all conditions in which it was tested. As a result of these studies it was postulated that the sawfly damage to solid-stemmed vulgare varieties could be expected to vary with variations in environmental condition. Golden Ball, on the other hand, could be expected to retain its resistance to a much greater degree.

The inheritance of solid stem in crosses between solid and hollow vulgare varieties was found by Platt *et al.* (16) to depend on three factor pairs. Platt and Larson (17) were unsuccessful in their attempt to transfer solid stem from Golden Ball durum to hollow-stemmed vulgare wheats. They suggest that there is a gene in the C genom that is epistatic to all other genes for solidness.

All of the solid-stemmed varieties that had been imported were agronomically undesirable when compared with existing Canadian varieties. Therefore, a breeding program was initiated to transfer their sawfly re-

sistance to agronomically desirable types. It was realized that in evaluating the lines produced in this program it would be necessary to develop an efficient, rapid technique to determine the reaction to sawfly of a large number of lines. In testing for sawfly resistance it was deemed necessary to study the effect of the insect on the plant and of the plant on the insect. Studies on the effect of the insect on the plant, i.e. the damage sustained by varieties in the various tests that have been conducted in the last six years, are summarized in this paper. Studies on the effect of the plant on the insect, i.e. the mortality and fecundity of the insect when reared on different varieties, will be reported in later papers.

PRELIMINARY EXPERIMENTS

Varietal Tests

In 1940 a total of 175 varieties of durum and vulgare wheat were grown at Swift Current in single rod row plots. They were exposed to a severe natural infestation of sawflies. At maturity the percentage of stems cut was determined by counts. The results showed that the durums as a class were resistant and that the solid-stemmed vulgare varieties were more resistant than the hollow ones. The results also indicated that varietal differences might exist within each of these groups. In general the commonly grown Canadian vulgare varieties were the most susceptible of the entire group.

A test of 24 varieties and hybrid lines was grown at Swift Current and Scott in the same year. The varieties were grown in single rod row plots, duplicated and arranged as randomized blocks at each point. The results showed a statistically significant variety—station interaction. It was thus apparent that in order to obtain reliable results it would be necessary to make tests at a series of stations.

Use of Cages

Considerable experience was gained in early experiments in the use of screen-wire cages for resistance studies. The varieties were grown on plots 4 × 6 feet in size and each plot was covered with a screen-wire cage. The number of sawflies required was then introduced into the cage. This method had two important advantages: first, the sawfly population on each variety could be controlled, and second, sawflies from different areas could be tested under comparable conditions. However, results were very disappointing because the resistant varieties failed to maintain their resistance under such conditions. For example, in one experiment S-615 (a resistant line) was cut 46% inside and 9% outside the cage; whereas Marquis (a susceptible variety) was cut 69 and 74% respectively. It is thought that the shading effect of the cages on the solid-stemmed lines reduced their solidness and hence their resistance. The cages have the additional disadvantage of being costly and the handling requires a large amount of labour. They offer little promise in the technique of testing varietal reaction in this type of resistance.

METHODS

With the preliminary results in mind, a series of uniform sawfly nurseries was established in 1941 and these are still being used. The general plan was to grow a series of varieties at a number of points throughout the sawfly area in locations that would expose the varieties to a severe

Area of severe infestation. Infestations have been generally severe during past ten years.

Area of light to moderate infestation. Infestations may build up to severe during a series of dry years but cropping practice and parasitism contribute to keeping pest under control.

Area of light infestation. Sub-marginal land, rolling topography, range land, with relatively small wheat acreage.

Boundary of dark brown soil zone.

Boundary of brown soil zone.

Locations of sawfly nurseries.

FIGURE 1. Map showing distribution of wheat stem sawfly in relation to soil zones.

natural infestation of sawflies. These nurseries were located at the Dominion Experimental Stations at Swift Current and Scott, at the Dominion Experimental Substation at Regina and the Dominion District Experimental Substation at Nobleford in each of the years 1941 to 1945; at the Dominion District Experimental Substations at Consort (1941–42), Riverhurst (1941) and Shaunavon (1943–45), and at the Dominion Experimental Farm at Brandon in 1942. The locations of these points are shown in Figure 1.

At each point the nursery was located on summerfallow adjacent to infested wheat stubble. The plots were placed at right angles to the source of infestation. This plan allowed for all plots to be equally exposed to infestation in so far as this was possible. The general plan of a typical nursery is shown in Figure 2. Each plot consisted of a single row 10 feet long. The rows were spaced 1 foot apart and each variety was seeded at the rate of approximately $1\frac{1}{4}$ bushels per acre. In 1941 and 1942 three replicates were used and in subsequent years five replicates. From 1941 to 1943 the varieties were arranged in randomized blocks and durum and

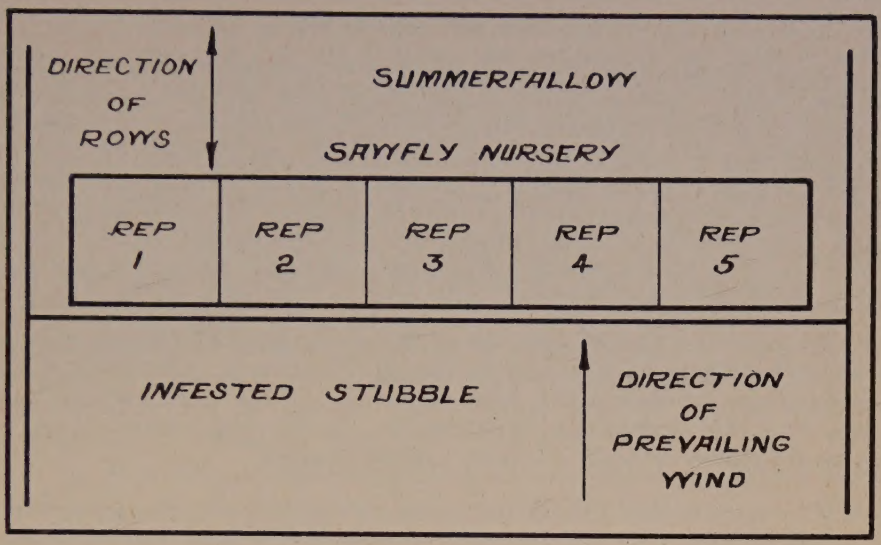

FIGURE 2. Field plan showing the location of a sawfly nursery in the field and the general plan of the nursery.

vulgare plots were intermixed. The two types were separated in 1944 when the 16 durum varieties were arranged in a complete lattice design and the 64 vulgare wheats in a quintuple lattice design (Goulden (11)). The blocks of the durum and bread wheats were randomized within each replicate thus allowing for a comparison within and between groups. Border rows were grown between durum and vulgare blocks in that year. A similar arrangement was used in 1945 except that border rows were dispensed with.

The nurseries were seeded early. According to Farstad (9) early seeded wheat is usually the most attractive to sawflies and may be expected to suffer the maximum damage.

Damage was estimated in the following manner. In 1941 the total culms in the plot and the number of culms severed by the larvae, excluding end plants, were counted about 10 days after the latest variety matured. This method was time consuming and laborious and would definitely limit the amount of material that could be handled. In 1942 the stubble from each row was lifted, bagged and shipped to Swift Current, and during the winter damage counts were made. This method proved very unsatisfactory; breakage of the stubble in handling and transit was difficult to differentiate from sawfly damage, the total labour required was great and the results delayed unduly. The following plan was adopted in subsequent years. Each of the authors made independent estimates of the percentage cut in each plot. The estimates were then compared and when discrepancies occurred the plot was re-examined and, if necessary, counts were made.

For the analysis of the data the percentage values were transformed to $\sin^2 \theta$ according to Bliss (3).

STUDIES ON INFESTATION

A variety will obviously escape damage if the adult fly fails to oviposit in the culms. Such a failure might result from inherent resistance to oviposition or from preferential oviposition where a choice of many varieties is available as in varietal test plots. Kemp (12) and Farstad (8) attribute resistance mainly to the ability of the variety to tolerate or destroy the egg or larva after it is deposited rather than to resistance to oviposition. However, their data suggest that differential oviposition may occur to a sufficient extent to be a factor in evaluating resistance. In fact, Kemp used the percentage of infested stems that were cut as a criterion of resistance.

In order to obtain information on the effect that differences in infestation were likely to have in varietal testing, 25 culms in each plot from 5 of the nurseries grown in 1941 were examined. These examinations were made soon after oviposition was complete. If the culm showed an egg or larva either alive or dead, it was considered infested.

TABLE 1.—MEAN PERCENT INFESTED AND NUMBERS OF VARIETIES DEVIATING SIGNIFICANTLY FROM THE MEAN IN THE 1941 NURSERIES. A TOTAL OF 64 VULGARE AND 24 DURUM VARIETIES WERE TESTED

	Species	Station				
		Scott	Swift Current	Noble-ford	River-hurst	Regina
Mean % infested	—	94	94	76	88	82
No. var. with significantly higher infestation than mean	*T. vulgare*	0	0	0	0	0
	T. durum	0	0	0	0	0
No. var. with significantly lower infestation than mean	*T. vulgare*	6	6	3	1	8
	T. durum	0	3	0	1	2

Statistically significant varietal differences in percentage infestation were established at each nursery, thus showing that certain varieties were infested to a greater degree than others. Some of the results obtained are summarized in Table 1. There were 17 different varieties out of a possible 24 represented in the vulgare wheats that had lower infestations than the general mean. No single variety was significantly lower at all stations. Fifteen of the 17 were late maturing varieties (a week or more later than Marquis). Two other wheats, *T. dicoccum* and *T. timopheevi* carried much lower infestations than any other varieties in the test. The former made very poor growth and had very fine stems that were apparently not attracrive to the insect, while the latter had densely pubescent culms which may have deterred the flies. When these wheats were caged in 1942 the sawflies oviposited freely, infesting them 100%.

The results show that none of the varieties tested had any particular resistance to oviposition, but they also show that some varieties partially escape infestation in varietal test plots. To the extent that they escape infestation they will also escape damage and hence will appear more resistant than they actually are. The question then arises as to whether percentage cut is a suitable index of resistance or if this figure should be

adjusted according to the infestation. To obtain information on this point the mean values, all Stations, for percentage cut were adjusted according to the mean percentage infested, all Stations, i.e., the percentage of the infested stems cut was calculated for each variety. These adjusted values were correlated with the figures for percentage cut. A correlation coefficient of 0.987 was obtained. This very high value was apparently obtained because the infestation of relatively few varieties deviated greatly from the general mean, and because of averaging the results from all Stations, and the relatively great differences between varieties in percentage cut as compared to the small differences in infestation. It is apparent that under the conditions prevailing in these tests differences in infestation, on the average, are of no particular importance in evaluating resistance. However, heavy infestations were obtained in the nurseries concerned and it is entirely possible that different results would be obtained if the mean percentage infested was 50 or less.

To determine accurately the infestation in a large series of plots is very laborious. It is relatively easy to determine infestation in hollow stemmed varieties as the lumen of the culm can be examined by splitting, but in solid-stemmed types it is much more difficult as the culm must be shaved off in thin layers and examined very closely, particularly for eggs and dead immature larvae. Furthermore this work must be conducted shortly after oviposition is complete as dead larvae tend to disintegrate and disappear. For these reasons the infestation was not taken on all plots in subsequent years, but in order to obtain further information on varietal reaction and on the uniformity of infestation throughout a nursery the following procedure was adopted:

1. When oviposition was complete the infestation in a series of susceptible hollow-stemmed checks was noted. This provided information pertaining to the extent and uniformity of the infestation throughout the nursery.

2. All plots that differed materially from the checks in stage of development, either through differences in rate of growth or as a result of rodent or other injury, were examined and the infestation noted. Similarily infestation was noted on all exotic types.

3. The infestation of one or two resistant checks was noted.

The results from these observations showed even less evidence of varietal differences in infestation than was obtained in 1941. This can probably be attributed to the fact that the very late maturing types that appeared in the 1941 tests were discarded and did not appear in subsequent years. In one nursery, Swift Current 1942, the infestation was not uniform throughout a replicate. This nursery was arranged in the field in a different manner from that shown in Figure 2. The replicates were placed side by side rather than end to end. The sawflies entered the nursery from the ends of the replicates and were few in number; hence one end of each replicate was heavily infested and the other end was practically free from infestation. As a result the nursery was abandoned and no data on damage to the varieties secured. This was the only nursery in all those conducted where the infestation was not uniform throughout. The failure of this nursery was largely due to an improper field arrangement.

REACTION TO DAMAGE

During the period 1941–45 a total of 28 nurseries were planted. Twenty-four of these yielded data on varietal reactions while four were failures and were discarded. One of the four failures, namely the 1942 nursery at Swift Current, has been discussed; a second failed because there were insufficient sawflies to produce damage; a third was discarded because of extensive parasitism of the sawfly larvae by *Microbracon cephi* (Gahan);

TABLE 2.—MEANS, STANDARD ERRORS, ETC. OF DATA ON SAWFLY DAMAGE TO WHEAT VARIETIES. PERCENT CUT TRANSFORMED TO $\sin^2 \theta$

Station	Year		Mean	S.E.	S.E. in percent.	Min. sig. diff.	F[3]
Scott	1941		44.5	4.02	9.0	11.2	14.10
	1942		25.8	3.20	12.4	9.0	5.72
	1943		37.1	3.21	8.6	8.9	21.48
	1944	(1)[1]	20.0	2.43	12.2	6.7	13.30
		(2)[2]	8.1	0.93	11.5	2.6	3.14
	1945	(1)	19.0	1.81	9.5	5.0	124.42
		(2)	34.2	6.02	17.6	16.7	4.76
Nobleford	1941		36.4	4.42	12.1	12.5	11.17
	1942		32.9	5.14	15.6	14.4	9.25
	1943		18.2	2.10	11.5	5.8	56.56
	1944	(1)	18.9	3.30	18.9	9.2	14.79
		(2)	6.6	1.61	24.5	4.5	1.77
	1945	(1)	17.1	2.45	14.3	6.8	56.02
		(2)	27.4	2.43	8.9	6.7	24.28
Swift Current	1941		40.0	4.83	12.1	13.5	3.59
	1943		30.6	3.34	10.9	9.3	21.83
	1944	(1)	44.8	3.50	7.8	9.7	44.95
		(2)	9.9	1.14	11.5	3.2	2.25
	1945	(1)	19.0	1.29	6.8	3.6	338.52
		(2)	11.6	1.10	9.5	3.1	14.18
Regina	1941		47.6	4.41	9.3	12.3	14.02
	1942		32.4	5.12	15.8	14.3	5.81
	1943		42.3	3.58	8.5	10.0	27.28
	1945	(1)	62.0	2.14	3.4	5.9	28.79
		(2)	35.8	2.35	6.6	6.5	11.23
Shaunavon	1943		37.8	3.00	7.9	8.3	35.14
	1944	(1)	34.3	3.04	8.8	8.4	42.44
		(2)	13.9	1.62	11.6	4.6	5.00
	1945	(1)	26.2	2.06	7.9	5.7	89.59
		(2)	36.2	2.79	7.7	7.7	16.99
Riverhurst	1941		38.1	4.37	11.5	12.2	6.34
Consort	1941		15.3	4.01	26.3	11.2	7.24
Brandon	1942		28.9	4.71	16.3	13.2	6.89

[1] Refers to test of varieties of *T. vulgare*.
[2] Refers to test of varieties of *T. durum*.
[3] All values except that for Nobleford, 1944 (2) exceed the one percent point.

while the fourth was a crop failure. The values for means, standard errors and F values for the 24 successful nurseries are presented in Table 2. Note that in this Table and in Table 4 the percentage cut has been transformed to $\sin^2 \theta$ and these are the only values used. The damage values together with the calculated errors cannot be transformed back to percentage figures, hence statistical differences between varieties can only be made on the bases of transformed values. For a discussion of this point see Cochran (4). Except for the test of durums at Nobleford in 1944 significant varietal differences were established in all nurseries.

During the course of the study many varieties and hybrid lines were tested. Space will not permit including data on all of these. Data on the damage sustained by some of the more common varieties of vulgare and durum are presented in Table 3. Upon request the authors would be glad to supply any data that are available on the reaction of particular varieties.

TABLE 3.—PERCENT CUTTING BY SAWFLIES IN WHEAT VARIETIES 1941–45

Variety	C.A.N.*	Percent cut					
		Av. 6 stat. 1941	Av. 4 stat. 1942	Av. 5 stat. 1943	Av. 4 stat. 1944	Av. 5 stat. 1945	Av. all stations
		Varieties of *T. vulgare*					
Apex	1909	69.8	53.5	74.7	55.1	82.6	68.3
Bena	1817	46.6	33.2	71.6	—	—	—
Cadet	3627	—	—	—	51.5	—	—
Caesium	1256	50.2	38.3	69.6	—	—	—
Canus	1260	59.9	46.0	65.3	—	—	—
Diament	1278	49.4	—	—	—	—	—
Garnet	1316	54.7	60.3	83.9	59.4	—	—
Gluford	—	50.7	36.7	60.8	—	—	—
Gluyas	—	15.9	25.3	38.8	—	—	—
Hope	1339	46.2	42.4	67.6	—	—	—
Indian Dwarf	—	—	25.4	—	—	—	—
Lohman's Wender	1387	48.4	—	—	—	—	—
Marquis	1831	61.2	41.6	68.7	52.6	79.2	61.8
McMurchay's Sel.	3626	62.5	—	—	—	—	—
Mida	3598	—	—	—	52.8	—	—
Milturum 0.321	1415	45.6	19.7	64.4	—	—	—
Nabawa	1818	—	—	—	45.8	—	—
Newthatch	3597	—	—	—	37.8	—	—
Ramona	3581	60.7	—	—	—	—	—
Red Bobs	1637	61.5	45.3	60.9	35.0	72.2	56.5
Regent	1938	52.2	39.3	62.2	47.6	80.0	57.2
Reliance	1503	65.0	44.6	67.4	—	—	—
Renown	1915	58.6	51.7	73.2	—	—	—
Reward	1509	60.4	54.7	67.6	44.4	—	—
Sultan	—	58.4	47.7	67.4	—	—	—
Thatcher	1820	60.9	47.6	69.2	43.8	75.9	60.7
Waratah	—	42.6	—	—	—	—	—
S-615	3577	14.1	22.6	10.6	4.0	16.3	13.6
S-633	3578	26.6	42.9	28.4	7.0	27.9	26.7
		Varieties of *T. durum*					
Aranautka	1213	34.1	5.1	—	—	—	—
Carleton	3527	—	—	—	3.3	33.2	—
Golden Ball	1325	11.2	5.5	5.4	0.8	9.0	6.8
Iumillo	1356	28.2	9.2	23.1	4.1	27.6	19.8
Kŭbanka	1386	27.2	9.6	19.2	—	—	—
Melanopus	1413	15.9	9.9	9.6	2.6	—	—
Mindum	1418	34.5	4.9	10.5	4.2	29.2	18.4
Monad	1778	22.7	4.2	11.6	—	—	—
Nodak	1427	28.9	—	—	—	—	—
Pelissier	1859	22.6	8.0	12.2	3.5	31.3	16.6
Sivousska No. 3	1523	17.4	8.3	7.9	3.6	20.1	12.2
Stewart	3599	—	—	—	4.8	40.7	—

* Canadian accession number.

None of the hollow-stemmed vulgare varieties has shown any high degree of resistance to sawfly attack. Nevertheless, differences among these types do exist. For example, Apex and Garnet were extremely

susceptible, whereas in most tests Regent and Red Bobs were considerably less so. A detailed comparison of the reactions of Apex and Regent is presented in Table 4. In all except two of the 24 nurseries the numerical damage values for Regent are lower than those for Apex, and in eight of the 24 the differences are statistically significant. No attempt has been made to investigate the characteristics that may be associated with these differences of susceptibility.

Differences were also found to exist among the solid-stemmed vulgare varieties. The two varieties S-615 and S-633 are equally solid-stemmed (14). The comparative data on the sawfly damage suffered by these varieties are presented in Table 4. In all cases S-633 had numerically higher ratings than S-615 and in 13 of the 24 nurseries the differences were statistically significant. Comparing S-615 (the most resistant solid-stemmed variety) with Apex (Table 4) it is noted that S-615 suffered significantly less damage in all nurseries. Compared with Regent, S-615 had numerically lower values in all nurseries and these differences were significant in 21 of the 24 trials.

The field appearance of resistant lines as compared with Apex (susceptible) is shown in Figure 3.

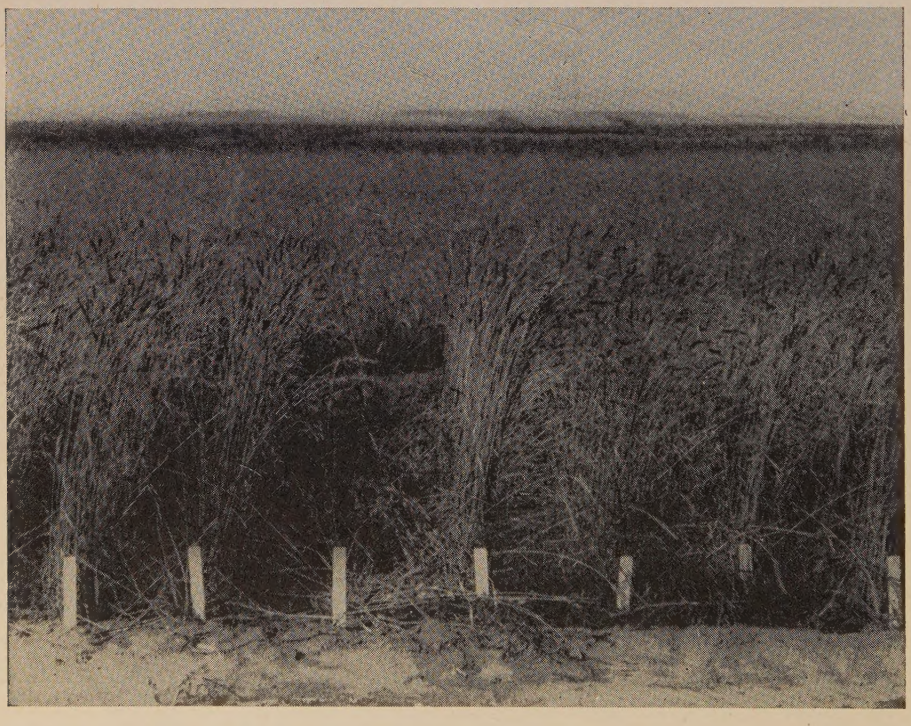

FIGURE 3. Sawfly damage to wheat varieties. Note the susceptible variety, left centre, as compared with resistant lines.

TABLE 4.—DAMAGE BY SAWFLIES TO WHEAT VARIETIES IN INDIVIDUAL TESTS, 1941–45. THE VALUES GIVEN ARE THE PERCENTAGE OF STEMS CUT TRANSFORMED TO SIN $^2\theta$

Station	Year	Percent cut transformed to $\sin^2\theta$						
		Apex	Regent	S-615	S-633	Golden Ball	Mindum	Nec. diff[1]
Scott	1941	71.1	56.4	29.8	34.0	17.8	39.6	11.2
	1942	33.4	25.3	24.1	35.5	12.3	12.5	9.0
	1943	58.9	48.2	20.9	33.8	19.1	21.8	8.9
	1944	31.3	26.4	9.0	11.9	3.8	7.2	6.7 and 2.6
	1945	64.1	60.7	8.8	16.8	12.8	34.9	5.0 and 16.7
	Av.	51.8	43.4	18.5	26.4	13.2	23.2	—
Nobleford	1941	55.8	38.8	26.4	28.7	12.8	32.1	12.5
	1942	59.9	47.8	27.5	38.5	10.2	10.6	14.4
	1943	43.0	32.7	6.2	17.3	3.4	3.4	5.8
	1944	31.7	30.9	1.6	10.1	4.3	7.8	9.2 and 4.5
	1945	51.7	56.4	7.4	17.6	7.3	36.8	6.8 and 6.7
	Av.	48.4	41.3	13.8	22.4	7.6	18.1	—
Swift Current	1941	56.3	39.2	22.9	41.5	27.6	41.5	13.5
	1943	60.6	49.2	15.2	35.7	9.8	15.9	9.3
	1944	70.8	61.6	14.1	22.2	6.0	10.1	9.7 and 3.2
	1945	68.2	60.1	6.0	18.7	5.8	12.6	3.6 and 3.1
	Av.	64.0	52.5	14.6	29.5	12.3	20.0	—
Regina	1941	74.1	57.7	18.8	34.9	17.4	43.1	12.3
	1942	48.9	34.4	30.5	52.4	9.6	6.6	14.3
	1943	72.8	69.8	24.8	42.0	10.2	14.5	10.0
	1945	77.4	74.1	58.8	69.7	28.0	29.6	5.9 and 6.5
	Av.	68.3	59.0	33.2	49.8	16.3	23.4	—
Shaunavon	1943	69.2	64.4	20.5	27.4	18.2	25.1	8.3
	1944	60.6	54.0	9.9	12.4	2.7	16.8	8.4 and 4.6
	1945	71.4	71.5	7.4	26.7	18.4	42.8	5.7 and 7.7
	Av.	67.1	63.3	12.6	22.2	13.1	28.2	—
Riverhurst	1941	50.6	50.4	15.4	25.4	18.7	41.5	12.2
Consort	1941	40.8	34.5	9.2	15.8	9.8	7.4	11.2
Brandon	1942	47.3	45.8	28.4	37.7	15.2	13.8	13.2
Average all stat.		57.1	49.6	18.5	29.4	12.6	22.0	—

[1]Where two values are given the first refers to vulgare varieties, the second to durum varieties.

Among the durums, Golden Ball was the most resistant (Table 3). This variety is solid-stemmed and had the greatest sawfly resistance of any wheat tested in these investigations. Melanopus and Sivousska 3 approached Golden Ball in resistance. These varieties are not solid-stemmed. Among the other varieties tested the differences were small. There is a suggestion that Stewart is somewhat more susceptible than the rest, but further data are needed before this can be verified.

The hollow-stemmed durums as represented by Mindum were much more resistant than the hollow-stemmed vulgares (Table 3). The difference between the hollow-stemmed durums and the solid-stemmed vulgares varied greatly from test to test, but on the average Mindum was slightly more susceptible than S-615 and slightly less so than S-633.

Effect of Environment

An examination of the data in Table 4 shows that the varieties differed in the amount of damage sustained during the same year at different stations, and during different years at the same station. The data were not considered sufficiently extensive to warrant a detailed study of these variations in relation to environmental factors, but an attempt was made to relate the differences to various weather data in order to see if any simple associations existed.

Seamans (18) found that weather conditions which produce a normal crop are most favourable for the sawfly. High rainfall or extreme drought resulted in fewer stems being cut. His observations were made on sawfly susceptible vulgare varieties. The results obtained in the present investigation were similar. Apex showed relatively small damage values at Scott in 1942 and 1944 (Table 4); both years were characterized by above normal precipitation. A similar situation occurred at Regina in 1942. On the other hand at Nobleford during 1943 and 1944 extreme drought conditions prevailed and again Apex showed relatively little damage. During seasons of high rainfall when plants are rank and succulent there is a high mortality among the larvae. This agrees with the observations previously made by Seamans (19). In addition it was noted, particularly at Scott in 1942, that the more or less continuous wet weather during ripening kept the base of the stems green and moist. Many of these stems, even though girdled by the sawfly, failed to fall over. In years of extreme drought the period between oviposition and the maturity of the crop is very short; presumably feeding conditions are poor due to lack of moisture in the stems and the high temperatures may be unfavourable to the larvae. Under such conditions larval mortality is high and damage decreased.

The reactions of the solid-stemmed vulgare varieties as exemplified by S-615 did not follow the pattern of Apex. Very probably the same factors were exerting their influence but other factors were masking the effect. Because light has been shown to affect the degree of solidness, and presumably the resistance, exhibited by solid-stemmed vulgare varieties, the percentage cutting in S-615 was correlated with hours of June sunshine. The negative value of 0.370 obtained was not significant ($N = 18$). That light can be an important factor is indicated in the results from Regina in 1945. In this test S-615 was cut 73% which was by far the greatest damage recorded for this variety under field conditions. At the same time there was some 60 hours less sunshine in June than in any other test on which records are available. It is possible that the low value of the correlation obtained may be due to lack of variation in light. With the exception of the test cited the hours of sunshine varied from 207 to 280. It would seem reasonable to suppose that after a certain minimum is reached further light would have little or no effect. If that minimum is in the neighbourhood of 200 hours then the variations in cutting that occurred are due to other causes. These could be the general effect of temperature and moisture and other factors that have not yet been investigated such as the nutrition of the plant and the sawfly.

The solid-stemmed durum, Golden Ball, retained its resistance under most conditions but even this variety showed considerable susceptibility in some tests. All durums tended to show high resistance under good

growing conditions. The coarse heavy stems produced under these conditions frequently failed to break over even when girdled. Under dry conditions resistance was sometimes high and sometimes low. No explanation suggests itself for the variations in cutting which occur during dry seasons.

The variability in reaction to damage is an interesting phenomenon. It also complicates the testing of hybrid lines. Further research may elucidate all the factors involved and make the interpretation of results of tests much simpler. However, it will probably be a long time before the breeder can determine the sawfly reaction of a hybrid line in a single test with the same accuracy as he can determine its stem rust reactions.

DISCUSSION

Despite the variability of the results it has been established that such solid-stemmed vulgare varieties as S-615 have a high degree of resistance to sawfly at most stations. In considering the damage sustained by this variety it should be kept in mind that the nurseries were located and handled in such a way as to obtain maximum damage. Only in exceptional conditions would a variety be subjected to such severe conditions under normal farming practice. That the resistance of S-615 can be transferred to agronomically desirable varieties seems highly probable (unpublished data). If this can be accomplished, immediate and substantial decreases in wheat losses may be expected. There remains the possibility that these decreases may not be permanent. In the first place there may exist physiologic races of sawfly to which such varieties would be susceptible. Physiologic races in Hessian fly have been reported by Painter (13). No evidence of specialized races of sawfly has been noted in this investigation. Even at Nobleford, Alberta, where a race of parthenogenetic flies exists (Farstad (7)), the varietal reaction is not significantly different from that in other areas where both sexes occur in approximately equal numbers. Nevertheless it is possible that such races exist. As yet no satisfactory technique has been developed for testing collections of flies at one point. Until such a technique is developed it will not be possible to appraise fully the status of physiologic races in evaluating resistance. In the second place the wide use of a highly resistant variety might tend to select a more virulent race of flies capable of causing greater and greater damage to the host. With this possibility in mind the characteristics of fly populations grown in various varieties have been studied. The results will be presented in a later paper. While tabulations are not yet complete, it appears that none of the populations studied is outstandingly virulent.

The differences in susceptibility among the hollow-stemmed vulgare varieties are not likely to be of any practical significance in reducing sawfly numbers. However, they are of interest because they demonstrate that factors other than stem solidness are involved in sawfly resistance. In view of this fact and in view of the varietal differences among solid-stemmed varieties, the question arises as to how close a correlation exists between stem solidness and resistance. Practical difficulties prevented a detailed study of this problem. Once a sawfly has tunnelled a stem it is usually impossible to determine whether or not it was solid. However, no hollow-stemmed variety has been found to have a high degree of resistance and no

solid-stemmed variety to be completely susceptible. Therefore, it would appear that the association is sufficiently close to be useful in a breeding program. Thus, it appears possible to select with a fair degree of accuracy for sawfly resistance on the basis of stem solidness.

The resistance exhibited by the durums makes them a useful crop for combatting sawfly infestations. Their usefulness is restricted by the limited market for this type of wheat and by the fact that the high quality durum varieties now available are inferior to the best vulgare varieties in yielding ability. The possibility of utilizing durum resistance in breeding vulgare varieties appears to be poor.

NOTES ON TECHNIQUE

In 1941 and 1945 the plots were arranged according to a lattice design, the durums in a complete and the vulgare in a quintuple lattice. The efficiency of these designs was compared with that of randomized blocks. The results are presented in Table 5. They show that important gains in efficiency were obtained by the use of lattice designs in a number of the nurseries. Furthermore, this type of plot design is much easier to use than randomized blocks in making field plans where large numbers of varieties are involved. The occasional gains of efficiency together with the ease of designing tests more than compensate for the extra calculations involved.

TABLE 5.—EFFICIENCY OF LATTICE DESIGNS AS COMPARED WITH RANDOMIZED BLOCKS IN TESTING FOR SAWFLY RESISTANCE IN WHEAT VARIETIES

Station	Efficiency in percent.			
	Varieties of *T. vulgare*		Varieties of *T. durum*	
	1944	1945	1944	1945
Scott	110	100	208	100
Nobleford	111	103	—	133
Swift Current	100	110	108	103
Shaunavon	100	139	118	103
Regina	—	102	—	128

It was observed that the main culms of hollow-stemmed varieties tended to be more susceptible than secondary tillers. The reverse was observed to be the case with solid-stemmed varieties. It was felt that differences in rate of seeding might affect relative reaction to sawfly by changing the proportions of tillers to main stems. Accordingly the four varieties S-615 (resistant), Hy-4131 (moderately resistant), Regent (moderately susceptible) and Apex (susceptible) were grown at four Stations in 1944. Each variety was seeded at the rates of $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 2 bushels per acre in a split plot replicated five times. The test at Nobleford was discarded because poor stands were obtained. At the other three stations, good stands were obtained and no significant differences in sawfly reaction between different rates of seeding were established. In these particular tests, growth was well above average with much more than normal tillering. Under drier conditions different results might have been obtained. Until

further evidence is obtained it is probably wise to seed varietal tests at approximately the same number of viable seeds per plot and at the regular rate of seeding for the area concerned.

The varietal tests reported in this paper were conducted in single row plots. The question arose as to whether one variety might not affect the reaction to sawfly of any adjacent variety because of differences in growth habit or other causes. In 1944 three varieties of durum and three of vulgare were grown in five row plots with the rows 1 foot apart at the four stations. Each variety was replicated three times and the durum and vulgare plots alternated. The sawfly damage of each row of each plot was noted. When the centre rows of the plots were compared with the outside rows (adjacent to another variety) no significant differences were found. These results indicate that one variety has no noticeable influence on adjacent varieties and that single row plots are suitable for varietal tests.

In conducting the varietal tests a good deal of local variation was noted. Local depressions or hummocks frequently gave very different results from the surrounding areas, even in places where these did not affect growth markedly. Where soil heterogeneity produced variable growth, sawfly damage was also variable. These variations made the estimating of damage more difficult and resulted in a loss of error control. As these tests were conducted on margins of fields, small hummocks of drift soil and dead furrows were numerous. Experience has shown that it is time well spent to choose as uniform a piece of land as possible and to prepare it carefully for seeding tests to determine sawfly resistance.

Permanent Testing Areas

At the present time there are many fields in any district within the sawfly area where varietal tests could be conducted with every assurance of obtaining maximum infestations. However, it is quite possible that with the introduction of resistant varieties or crops, or by changes in farming practices, sawfly numbers may be greatly reduced or their characteristics changed. From the viewpoint of research it seems desirable that certain small areas be set aside where adequate populations can be maintained. In 1941 a 3-acre plot at Swift Current was selected for this purpose. This area is surrounded by grassland, chiefly *Agropyron cristatum* (L) Beauv. for a mile or more in each direction. The plot was divided into narrow strips. It was cropped as a 2-year rotation of fallow and wheat. Every second strip that was in crop each year was seeded to Apex, a susceptible variety. The other crop strips were used for varietal testing or other purposes. Sawflies were introduced in small numbers in 1941 and by 1943 the population was large enough to completely infest all stems. Infestations of 100% were also obtained in 1944 and 1945. These results would indicate that it is possible to set up permanent testing areas on quite a small acreage. Similar testing areas are in the process of development at the Dominion Experimental Stations at Lethbridge and Scott. Difficulties may be experienced in maintaining testing areas either through crop failures or by an invasion of parasites. With this in mind it would seem very desirable that additional permanent testing points be established in the sawfly area as soon as possible.

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SUMMARY

The reaction of wheat varieties to sawfly damage was determined by field trials. Uniform testing nurseries were established at various points throughout the area infested by sawfly. Varieties were grown in single 10-foot rows replicated three, and, in later nurseries, five times. The nurseries were located adjacent to infested wheat stubble. The criterion of damage found most satisfactory was the average of two independent estimates of percentage of the stems cut. Using these methods highly significant varietal differences were established in 24 of the 28 nurseries seeded. Hollow-stemmed varieties of *T. vulgare* were generally susceptible, solid-stemmed varieties of *T. vulgare* and varieties of *T. durum* generally resistant. Varietal differences within each group were also established. The hollow-stemmed vulgare varieties suffered greatest damage under average growing conditions and least when subjected to heavy rainfall or extreme drought conditions. It is suggested that the reaction of solid-stemmed varieties is modified by rainfall, hours of sunshine, and probably other factors, the exact nature of which could not be demonstrated with the data available. Durum varieties had high resistance in wet years and variable reactions in others. The use of lattice designs increased the efficiency of the tests in a number of cases. Different rates of seeding did not significantly affect varietal reactions. Single row plots appeared satisfactory as no evidence was obtained that any variety affected the reaction of an adjacent one. Testing points with a high degree of soil heterogeneity gave extremely variable reactions to sawfly. The advisability of establishing small, permanent areas where large sawfly populations may be maintained for experimental purposes is discussed.

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THE EFFECT OF SEED TREATMENT AND DATES OF SEEDING ON THE EMERGENCE AND YIELD OF PEAS[1]

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Garden peas are widely grown in Saskatchewan although not on a commercial scale. Serious trouble is not usually encountered in obtaining satisfactory field stands; however, from time to time our attention is drawn to plantings where the emergence is very poor. In this province, information on certain aspects of pea culture is limited and because of this the present study was undertaken.

The literature on testing of seed treatment materials is extensive, both in Europe and America. In general the wrinkled-seeded varieties have shown decided benefit from treatment but this is dependent in large degree on seed and environmental conditions. Reports on temperature, moisture and soil type in relation to seed decay have shown the importance of these factors on resultant plant stands. Walker *et al.* (8) refer to a good deal of the relevant literature and report their findings as to the effectiveness of 2% Ceresan and red copper oxide on smooth and wrinkled-seeded pea varieties. Baylis *et al.* (2) present data relating to the effects of soil temperature, moisture and seed treatment on the emergence of peas. The present study reveals general agreement with the findings of other workers, although the effect of planting date as reported here is at variance with much of the published literature.

EXPERIMENTAL METHODS

Field tests were conducted for three consecutive years, beginning in 1943, dealing with the effects of seed treatments and dates of planting on the emergence and yield of garden peas. In 1943, Laxton's Progress and Lincoln were used and in the two following years the latter variety was used exclusively. Planting was done at three dates in 1943 and 1944 and at four dates in 1945, commencing in the spring as soon as the soil was ready. The plots were on a different portion of the same field each year, on summer-fallow. The soil is classed as clay loam and has a moderately high moisture holding capacity. In 1943, seed treatments used were Semesan and Spergon; the following year, Ceresan and Arasan were added; and in 1945, Du Bay 1452F, which contains 7.7% ethyl mercury p-toluene sulphonanilide, was also included making a total of five treatments in that year. Rates of treatment expressed as a percentage by weight of the seed were as follows: Ceresan, 0.1%; Spergon, 0.2%; Semesan, 0.25%; Arasan, 0.2%; and Du Bay, 0.1%. Treatment was done not more than four days and not less than 2 days prior to planting in every case and the seed was sown with a Kemp V-belt seeder. Planting dates were as follows: 1943, April 26, May 7 and May 18; 1944, April 27, May 8 and May 24; 1945, May 3, May 15, June 4 and June 18. All tests were randomized and replicated in accordance with recognized field plot procedure and the results were analyzed statistically. Some of the seed samples were commercial, others

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were hand threshed from our own plots. Soil temperatures at seed level were kept in 1944 and 1945, and in 1943 soil temperatures at the 6-inch level as well as air temperatures are available. Records of rainfall are likewise at hand for each year. The emergence counts were taken only after sufficient time had elapsed for maximum emergence to have taken place. Yields were based on weights of unshelled green peas. In 1943, pickings were made at several intervals throughout the season but in 1944 and 1945, due to scant rainfall, it was found that two pickings from each planting separated by a 10-day interval accounted for practically all pods produced.

EMERGENCE DATA FROM FIELD TESTS

Effect of Seed Treatments

The emergence data obtained from field tests in 1943, 1944 and 1945 are presented in Tables 1 and 2. In Table 1 the effect of treatment on each seed sample is shown for each of the three years. The dates of planting were averaged and are not shown separately. In Table 2, dates of seeding are shown separately for each year. In the columns, "treated", the percentages refer to the average of all treatments used.

Table 1.—The effect of seed treatments on the emergence of garden peas

Treatment	Emergence					
	1943		1944		1945	
	Laxton's Commercial	Lincoln Commercial	Lincoln Hand-threshed	Lincoln Commercial	Lincoln Composite*	Lincoln Commercial
	%	%	%	%	%	%
Check	45.5	74.0	88.0	52.0	67.5	60.0
Semesan	74.0	78.5	88.5	81.5	78.0	78.0
Spergon	67.5	72.5	92.0	73.5	75.0	75.0
Ceresan			94.0	76.5	79.5	72.0
Arasan			92.0	72.0	78.0	72.5
Du Bay					71.0	71.0

* Composite sample composed of two-thirds commercial and one-third hand-threshed seed.

Table 2.—The effect of dates of planting on the emergence of untreated and treated garden peas

Year	Sample	Seed	Emergence							
			Date 1		Date 2		Date 3		Date 4	
			Check	Treated	Check	Treated	Check	Treated	Check	Treated
			%	%	%	%	%	%	%	%
1943	Laxton's	Commercial	81	88	32	58	24	66		
	Lincoln	Commercial	89	88	75	77	59	61		
1944	Lincoln	Hand-threshed	96	95	83	88	85	90		
	Lincoln	Commercial	82	89	47	74	27	64		
1945	Lincoln	Composite	82	82	76	82	53	78	58	63
	Lincoln	Commercial	75	83	66	75	47	71	53	65

Wide variability in the effect of seed treatments on different samples is evident in Table 1. This was particularly true in 1943 and 1944. In these years, the general level of emergence was widely different between the two samples used each year. The greatest improvement due to treatment occurs, of course, where the seed is for some reason low in vigour. In 1943 the Laxton's variety was not examined closely but in outward appearance it was reasonably good. In 1944 the commercial sample of Lincoln appeared almost as good as the hand-threshed sample. Careful examination, however, showed about 20% of the seeds had slight cracks and abrasions of the seed-coat. This is considered to be one cause of its poor performance. The analysis of the 1943 data showed Semesan to be significantly better than Spergon in giving a maximum stand of plants. In 1944 no one treatment was significantly better than any other although Ceresan and Semesan averaged slightly better than Spergon and Arasan.

In 1945 a general improvement is attributable to treatment. Table 2 shows that the increase was chiefly at the second, third, and to a lesser degree the fourth dates of planting. No significant differences were found between Ceresan, Semesan, Spergon and Arasan; however, the emergence of the Du Bay treated seed was significantly lower than that of Ceresan and Semesan but not significantly lower than the emergence of Spergon and Arasan treated seed. Thus in all three years there is a suggestion that the mercurial dusts Ceresan and Semesan are slightly better than the non-mercurials in promoting a maximum stand of plants. The data obtained from only one year's experimentation with Du Bay 1452 F, also a mercurial dust, probably do not warrant a statement as to its effectiveness at this time.

Effect of Moisture and Temperature

It is quite apparent from Table 2 that in the 3-year period the highest emergence, regardless of the condition of the sample, was at the earliest date of planting. There was, in general, a decline in emergence with each subsequent planting and, while this trend was not absolute, it was very striking. It was sharper in the untreated than in the treated seed; that is, the effect of treatment was to maintain good emergence at all dates. There was a very substantial difference between samples in their ability to emerge well at all plantings. Some samples fell off markedly at the second and third dates, while others showed only a small decline. Considering the entire emergence data, perhaps the most apparent trend is the reduction in emergence with each later date of planting.

In an attempt to explain the relationship between date of planting and emergence, two factors come immediately to mind; viz., moisture and temperature. It has been shown by numerous workers, among them Hull (4), Jones (6), and Baylis (1), that high soil moisture accentuates pre-emergence damping-off and thus reduces stand. Further, they report this to be worse at low than at high temperatures. Baylis makes the following statement, "Whereas the effect of soil temperature has been inadequately studied, more especially as regards the action of the various pathogens, it has become clear that soil moisture is the predominating factor; viz., the higher the soil moisture the more severe the disease." McNew (7) reports that in tests under controlled conditions at 58°, 67°, 76°, and 90° F., seed decay by

Pythium ultimum becomes less severe with each increase in temperature. With the foregoing observations and experimental results in mind, a study was made of temperature and rainfall in relation to the various dates of planting in 1943, 1944, and 1945. In Table 3, the effect of date of planting on untreated seed is shown for each of the three years. Samples 1 and 2 refer to Laxton's Progress and Lincoln respectively in 1943, and in 1944 and 1945 Sample 1 refers to the hand-threshed and composite samples of Lincoln respectively. Sample 2 in the two latter years is also the Lincoln variety and in both cases is commercial seed. The rainfall shown in Table 3 is for a period inclusive of two days before and six days after each date of planting.

TABLE 3.—THE EFFECT OF DATE OF SEEDING ON EMERGENCE OF PEAS

Year	Dates of seeding	Rainfall	Emergence	
			Sample 1	Sample 2
		inches	%	%
1943	April 26	0.48	81	89
	May 7	Nil	32	75
	May 18	0.15	24	59
1944	April 27	1.05	96	82
	May 8	Nil	83	47
	May 24	1.20	85	27
1945	May 3	0.24	82	75
	May 15	0.11	76	66
	June 4	0.13	53	47
	June 18	Nil	58	53

As pointed out by McNew and others, rainfall is most severe in depressing emergence if it occurs soon after seeding. In 1943 and 1945, spring precipitation was limited and none of the dates of seeding were followed closely by appreciable amounts of rain; however, there was always sufficient moisture to promote good germination.

In 1944, April precipitation amounted to only 0.26″, most of which fell on April 14. Following the first planting on April 26, rainfall of 1.32″ fell during the first three days of May. There was no further precipitation until May 17, 18 and 19 when 0.39″ was received. Thus the second planting made on May 8 was neither preceded nor succeeded closely by rainfall, yet the emergence particularly in the poorer sample was very severely reduced. On May 23 a heavy shower occurred in which 1.20″ of rain fell. Warm, sunny weather on the following day dried the soil sufficiently so that planting with the seeder could be satisfactorily accomplished. This was done on May 24, and no further rainfall of consequence is recorded until July 1. Whether this rain closely preceding the third planting had an effect in reducing the emergence is difficult to say. The emergence in the commercial sample shows a definite reduction from the second date, yet the second date showed an equally substantial reduction from the first date and rainfall both before and after that planting was lacking.

From field observations and study of the rainfall data, the writer is of the opinion that the decreases in emergence as the season advanced were little affected by deviations from satisfactory soil moisture. That excess soil moisture may be a factor in causing pre-emergence killing is not questioned. Greenhouse tests with controlled watering demonstrated this clearly. The point to be stressed is that in 1943, 1944 or 1945 the percentage emergence followed a fairly definite pattern, decreasing as the season advanced, and this could not be correlated with moisture conditions.

In an appraisal of soil temperatures, there appears to be reasonably good correlation between increasing temperatures and decreasing emergence. The temperature was lowest at the first date of seeding and in general increased as the season advanced. The emergence was highest at the first seeding and decreased as the season advanced. Table 4 shows the average emergence of the untreated rows at each planting and the average mean temperature for a certain period following each date of planting. These periods have been chosen arbitrarily and are intended to approximate roughly the germination phase of the seed. They are 10-, 8-, 6-, and 6-day periods for the 1st, 2nd, 3rd and 4th dates of planting respectively. The temperatures shown are air temperatures in 1943 and soil temperatures at seed level in 1944 and 1945. Figure 1 shows the emergence of untreated peas in percentage at each date of planting and the average mean temperature for a period following each date of planting.

TABLE 4.—THE EFFECT OF TEMPERATURE ON EMERGENCE OF UNTREATED GARDEN PEAS

Year	1st Date		2nd Date		3rd Date		4th Date	
	Emerg.	Temp.	Emerg.	Temp.	Emerg.	Temp.	Emerg.	Temp.
	%	°F.	%	°F.	%	°F.	%	°F.
1943	85	44.0	53	39.0	41	66.0		
1944	89	47.6	65	53.7	56	66.2		
1945	78	37.8	71	43.3	50	54.9	55	64.4

Table 4 and Figure 1 indicate a correlation between temperature and emergence but they do not suggest that it is a simple relationship. For instance, the greatest decline in emergence is at the second date of planting, and the temperature difference between the first and second planting is slight each year. In fact it was higher at the first than at the second date in 1943. In 1943 the temperatures reported are air rather than soil; however, comparison of air and soil temperatures at the $2\frac{1}{2}$-inch level in 1944 and 1945 did not indicate wide differences. The air temperatures were frequently higher than soil temperatures on warm cloudy days, and on sunny days the reverse was true. In 1944 and 1945, the soil temperatures were on the average about 6° F. higher at the second than at the first date.

The results presented here dealing with temperature relations are at variance with those reported by Brett *et al.* (3), Hull (4), McNew (7), and others. They are, however, in line with tests carried out by Hutton (5) in Australia who found that the mean percentage field emergence varied from one planting to the next, the tendency being towards poorer emergence

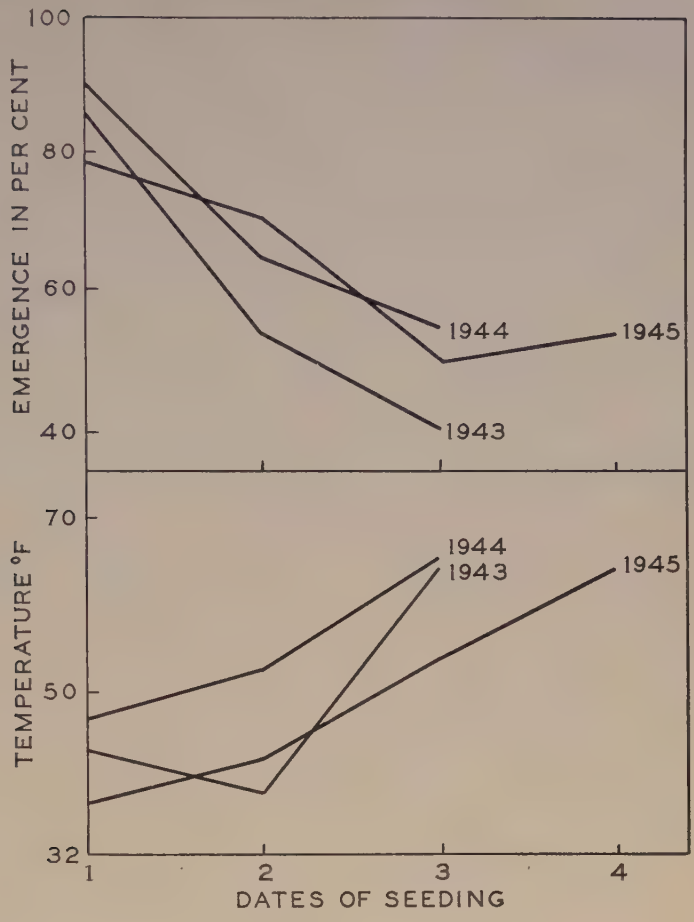

FIGURE 1. The relation between temperature and emergence of untreated garden peas. Air temperatures are shown in 1943 and soil temperatures at seed level in 1944 and 1945. They are the average mean temperatures for 10-, 8-, 6-, and 6-day periods following the first, second, third, and fourth dates of seeding respectively.

as the season advanced from cool spring to hot summer. The explanation of this differing response to temperature in widely separated geographic areas is not entirely clear. The main causal agent in pre-emergence blighting is reported to be *Pythium ultimum* in England and parts at least of the United States (1, 7, and others). No detailed study was conducted to identify the pathogens concerned in pre-emergence killing in the field work reported here. However, in greenhouse tests, peas in the untreated rows were dug up from time to time and examined. In most cases where germination was not progressing, the seed was surrounded by a dense mycelial growth. Isolations nearly always yielded a phycomycetous organism. Professor T. C. Vanterpool kindly examined two of these cultures, which he identified as *P. ultimum*. From this it appears quite possible that this is one of the important pathogens in Saskatchewan. Baylis *et al.* (2) found low temperatures such as would correspond to our first date of seeding to be favourable for pre-emergence blighting. But,

under our conditions, emergence was good at the first date. The writer suggests that in Saskatchewan the pathogens would be at a low ebb after the cold of winter and would require a certain period in the spring to initiate vegetative growth and increase to a more or less normal level. The first planting each year coming as soon as the soil was suitable for cultivation may have allowed the peas a period sufficiently long to pass the stage when they would be most susceptible before the fungi had increased appreciably. Further work is to be carried out to test the validity of this theory.

YIELDS IN 1943, 1944, AND 1945

Each year, yields of unshelled green peas were obtained. Several pickings from each date of planting were taken in 1943, but in the two following years rainfall was light and two pickings from each seeding date separated by about 10 days accounted for practically all pods produced. The 1943 yields, where the dates of picking were not kept separate, show that significant differences in yield were coincident only with large differences in emergence. Significantly higher yields in the treated rows were obtained in the variety Laxton's Progress at the second and third dates of seeding. It is generally known that in field tests where rainfall is a limiting factor the thinner stands, if not subject to weed competition, will often give as heavy a yield as the thicker stands of plants.

In 1944 and 1945, yields for the first date of harvest were two or three times as heavy as for the second date of harvest. The yields from the treated rows, at the first picking, were considerably heavier than from the untreated rows. This is more particularly true at the second and third planting dates where the stand of the untreated rows was reduced seriously. At the second date of harvest, the untreated rows gave the best yield. Table 5 shows the total yield in pounds from the untreated rows and the average of the total yields from the treated rows at each date of harvest. Also shown is the percentage increase or decrease in yield due to treatment.

TABLE 5.—YIELDS OF PEAS FROM UNTREATED AND TREATED SEED AND EFFECT OF TREATMENT ON YIELD

Year	Treatment	First harvest		Second harvest		Total yield	
		Yield	Percentage of check	Yield	Percentage of check	Yield	Percentage of check
		lb.	%	lb.	%	lb.	%
1944	Check	36.9		16.5		53.4	
	Treated	44.4	119.7	12.0	62.4	56.4	105.2
1945	Check	31.4		17.2		48.6	
	Treated	34.4	108.5	14.5	81.5	48.9	100.4

Total yields for the season showed no significant differences due to treatment either in 1944 or 1945, but at the first date of harvest the treated seed produced a significantly better yield than the untreated, while at the second date the reverse was true. It seems reasonable to assume that available moisture was the factor involved. Thus, the treated rows with their thicker stand of plants produced a heavier crop at the first date of harvest but in so doing they exhausted the soil moisture to a greater extent

than did the untreated rows. The untreated rows, due to their more favourable moisture reserve, gave a heavier yield than the treated rows at the second harvest.

GREENHOUSE TESTS

Two samples of peas were selected for a greenhouse temperature test in the fall of 1944. One was the wrinkled garden variety, Lincoln, and the other a round-seeded field variety, Dashaway; 35% of the kernels in the former variety showed injury to the pericarp in the form of slight fractures and abrasions, and in the Dashaway sample about 20% of the seeds were thus affected. Two hundred sound and a like number of injured seeds were selected from each sample. One-half of the sound and one-half of the injured seeds of each sample were treated with 5% Ceresan at a rate of 0.1% by weight. The peas were planted in duplicate, in beds in adjoining sections of the greenhouse, one bed maintained at an average temperature of 20° C. and the other at 8° C. The soil for both beds was taken from a well-mixed pile which was at a moisture level of approximately 48% of its moisture-holding capacity. The warm bed received a light watering four days after planting; and the cool bed, eight days after planting. Emergence in the former reached a maximum after 10 days; and in the cool bed, after 26 days. Table 6 shows the percentage emergence of the untreated and treated seed of each sample at each temperature.

TABLE 6.—EFFECT OF DIFFERENT TEMPERATURES ON EMERGENCE OF TWO VARIETIES OF PEAS IN THE GREENHOUSE

Sample	Condition	Emergence			
		20° C.		8° C	
		Check	Ceresan	Check	Ceresan
		%	%	%	%
Lincoln	Sound	64	94	80	92
Lincoln	Injured	6	70	48	66
Dashaway	Sound	60	82	40	72
Dashaway	Injured	18	42	6	40

In this test, seed treatment was very beneficial. Even in the sound seed, good increases may be attributed to it and in the injured seed the response was very substantial. The data also give evidence on a point which has been observed several times elsewhere; that is, the apparent different reaction of these two pea varieties to temperature. Lincoln peas have been shown to germinate best at low temperatures while Dashaway appears to give a better stand when the soil is warm.

A fairly extensive test was conducted in 1945 in which 10 samples of field peas, treated and untreated, were planted in the field. The emergence data from this test showed that every sample gave a much better stand at the second than at the first date of planting. It is realized that in a field test, variables other than temperature may enter into the picture so that several seasons' results supplemented by controlled tests in the greenhouse would be required to settle this point definitely. However, the results outlined here and supplemented as they are by limited greenhouse work are indicative that field peas of the variety Dashaway differ in their temperature relations to garden peas of the Lincoln variety.

DISCUSSION AND CONCLUSIONS

In field tests conducted in 1943, 1944 and 1945, garden peas were dusted with certain fungicides and planted in the field at several dates. Generally speaking, the emergence was best in the early sown peas and became progressively poorer with each subsequent planting. A decided benefit resulted from seed treatment at the later dates of planting and in the poorer samples. A number of studies dealing with the effect of seed treatment and soil moisture and temperature are reported in the literature. The findings are mainly in agreement that seed treatments are beneficial, their value depending on seed and environmental conditions. The data presented here indicate that the same is true at Saskatoon. In England and the United States of America, the cardinal factor in pre-emergence killing has been shown to be excessive soil moisture and, perhaps more particularly, rain soon after planting in its tendency to compact the soil around the seed, providing moist, poorly aerated conditions. Soil temperature has been given a minor role by English workers but in general they consider higher temperatures as being conducive to maximum emergence in garden peas. In the United States, McNew (7) found progressively less seed piece decay with each increase in temperature from 58° through 67° and 76° to 90° F. Dates of planting in the tests reported here have shown best emergence at the earliest date. The progressive decrease in emergence with each subsequent planting, particularly in the untreated rows, could not be correlated with changes in the soil moisture or with rain soon after planting. The temperatures from one planting to the next did, however, follow a more or less definite pattern, increasing as the season advanced. Scrutiny of the data suggests that the relationship between emergence and temperature is not a simple one. Possibly there is a delicate balance between soil temperature and the organisms causing pre-emergence blighting. The emergence data show in most cases an abrupt decrease between the first and second planting dates. The temperature during this interval changed only slightly on the average. It is suggested that *P. ultimum* and other organisms concerned in pre-emergence blighting require a period in the spring to initiate active vegetative growth. Early planted peas may have passed their susceptible stage before the fungi have increased sufficiently to cause much seed decay. The results reported here dealing with dates of planting are apparently in line with those of Hutton (5) in Australia who found a tendency toward poorer emergence as the season advanced from cool spring to hot summer.

In the matter of yield in garden peas, field results indicate little or no gain to be derived from seed treatment when the total yield for the season is used as a basis. However, the 1944 and 1945 tests show that the yields at the first harvest reflect fairly closely the thickness of stand; that is, the improved stands brought about by seed treatment outyield the thinner stands in untreated rows at the first date of harvest but the lighter stands did not use up available moisture as rapidly and so at the second harvest they were the heavier producers.

All of the treatments tested; i.e., Ceresan, Semesan, Arasan, Spergon, and Du Bay 1452F were effective, with perhaps some slight advantage in

favour of the mercurial dusts, Ceresan and Semesan. Du Bay 1452F in one year's trials and at one rate of application appeared to be slightly less effective than the others.

In a greenhouse temperature test, Lincoln peas, a garden variety, gave a better stand of plants at 8° C. than at 20° C., while with Dashaway peas, a field variety, the reverse was true. Likewise in one year's field trials, smooth-seeded field varieties emerged better at the second than at the first date of planting. These results suggest that the effect of temperature is at least in part on the host and that garden and field peas differ in their temperature requirements.

SUMMARY

Seed treatment of garden peas proved to be generally conducive to increased emergence and sometimes to increased yields at Saskatoon. The early sown peas emerged better than later planted ones, and seed treatment had its greatest effect on the latter. When total yields for the season were taken as a basis, only the severe reductions in emergence were reflected in reduced yield. However, yields at the first date of harvest were much more closely indicative of the emergence. In most cases, the treated rows produced heavier yields than the untreated ones at this date of harvest.

A comparison of emergence data with moisture conditions at the different dates of planting and with temperatures prevailing during the germination phase indicated that the emergence correlated fairly well with temperature but not with moisture. According to results presented here, soil temperature may be considered an important factor in determining the emergence of garden peas. Limited tests with smooth-seeded field pea varieties indicated that they were favoured by higher temperatures than were garden peas during their germination phase.

ACKNOWLEDGMENTS

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THE RELATIONSHIP OF MOISTURE CONTENT AND YEAST COUNT IN HONEY FERMENTATION[1]

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Various authors have pointed out that there exists a relationship between moisture content and the fermentation of honey. The relationship, however, has never been established on the basis of yeast infection which is the recognized cause of spoilage. Consequently a statistical treatment of the microbiological and moisture analyses of honey samples from all producing areas in Canada has been undertaken to determine this relationship.

LITERATURE

Fabian and Quinet (2) suggested that the critical moisture content of honey is approximately 21%. Methods of determining the amount of moisture have changed and according to present tables in use their 21% is equivalent to 19.6%. Landerkin (3) states that the critical moisture content of honey is about 19%, while Lochhead (5) has illustrated how yeast and moisture content may be considered in predicting the length of time honey may be stored safely.

The author (8) has reported the relationship of moisture content and yeast count to the keeping quality of honey, based on observation of nearly 900 samples in storage. Some of these honeys had been heated during the extracting and canning process, and, since more recent work at the Bee Division, Central Experimental Farm, Ottawa, has revealed that even a mild application of heat has a lethal effect on honey yeasts, it has been necessary to reconsider the results. These and additional data have been treated statistically, and the present paper reports a correlation between moisture content and yeast count and discusses the relationship of these to fermentation and storage.

EXPERIMENTAL

Duplicate samples of honey representing a fairly even geographical distribution were obtained from the various producing areas in Canada. Records of source, treatment, and method of handling were obtained in each case. One set of these duplicates was stored at room temperature, while the other was used for physical, chemical, and microbiological analyses.

Storage samples were examined periodically for signs of fermentation, rate of granulation, and changes in physical condition. The corresponding samples were tested for colour, moisture, sucrose, invert sugars, nitrogen, other chemical components[3], and yeasts.

All honeys were tested for moisture content by the refractometer method. At first the refractive indices as prepared by Schönrock (7) were used, but, later, when Chataway's tables (1) became available, the earlier

[1] Contribution from the Bee Division.
[2] Assistant (Apiary products).
[3] For consideration of the changes in chemical constituents in storage see Progress Report of the Division of Chemistry, 1930–33, published 1935.

work was revised[1]. The grades used are those defined in The Fruit, Vegetable and Honey Act (10). The yeast counts on the 1929, 1931, and 1935 samples were made by the dilution method described by Lochhead and Heron (4), numbers being estimated according to McCrady (6). The crops of 1936, 1937, and 1938 were analyzed by the plate count method.

RESULTS AND DISCUSSION

Moisture Content and Fermentation

Table 1 shows the way in which the samples of honey were grouped according to moisture content, together with the number and percentage fermenting within a year in each group.

Table 1.—Distribution of unheated samples of Canadian honey according to moisture content for six crops

Moisture	Samples	1929	1931	1935	1936	1937	1938	All years
%								
Under 15.1	No. of samples	15	10	2	22	5	8	62
	No. fermented	0	0	0	0	0	0	0
	% fermented	—	—	—	—	—	—	—
15.1–16.0	No. of samples	35	36	12	37	22	38	180
	No. fermented	1	1	0	0	0	3	5
	% fermented	2.9	2.8	—	—	—	7.9	1.8
16.1–17.0	No. of samples	67	32	24	54	42	61	280
	No. fermented	8	3	1	0	4	10	26
	% fermented	11.9	9.4	4.2	—	9.5	16.4	9.3
17.1–18.0	No. of samples	47	27	41	37	52	41	245
	No. fermented	17	19	8	6	21	28	99
	% fermented	36.2	70.4	19.5	16.2	40.4	68.3	40.4
18.1–19.0	No. of samples	13	17	20	14	25	11	100
	No. fermented	6	15	12	7	14	9	63
	% fermented	46.2	88.2	60.0	50.0	56.0	81.8	63.0
Over 19.0	No. of samples	4	3	10	9	14	5	45
	No. fermented	4	2	5	6	10	5	32
	% fermented	100.0	66.7	50.0	66.7	71.4	100.0	71.1
Entire range	No. of samples	181	125	109	173	160	164	912
	No. fermented	36	40	26	19	49	55	225
	% fermented	19.9	32.0	23.9	11.0	30.6	33.5	24.7

When plotted out (Figure 1) it is seen that percentage fermentation increases most appreciably in the region between 17 and 18%, falling off somewhat near the latter point and finally reversing direction beyond 19%.

The marked increase in fermentation in the 17.0 to 18.0% zone is of significance in the case of grading, as is evident in Table 2. The Fruit, Vegetable, and Honey Act (10) states that Grade I honey shall not contain more than 17·8% moisture; Grade II not more than 18.6%; and Grade III not more than 20%. Honey containing more than 20.0% of moisture is outclassed by the Food and Drugs Act (9), hence has been marked "Out" in Table 2.

[1] This fact explains the discrepancies existing between tables in the text and those published by the Bee Division and the Divisions of Bacteriology and Chemistry prior to 1935.

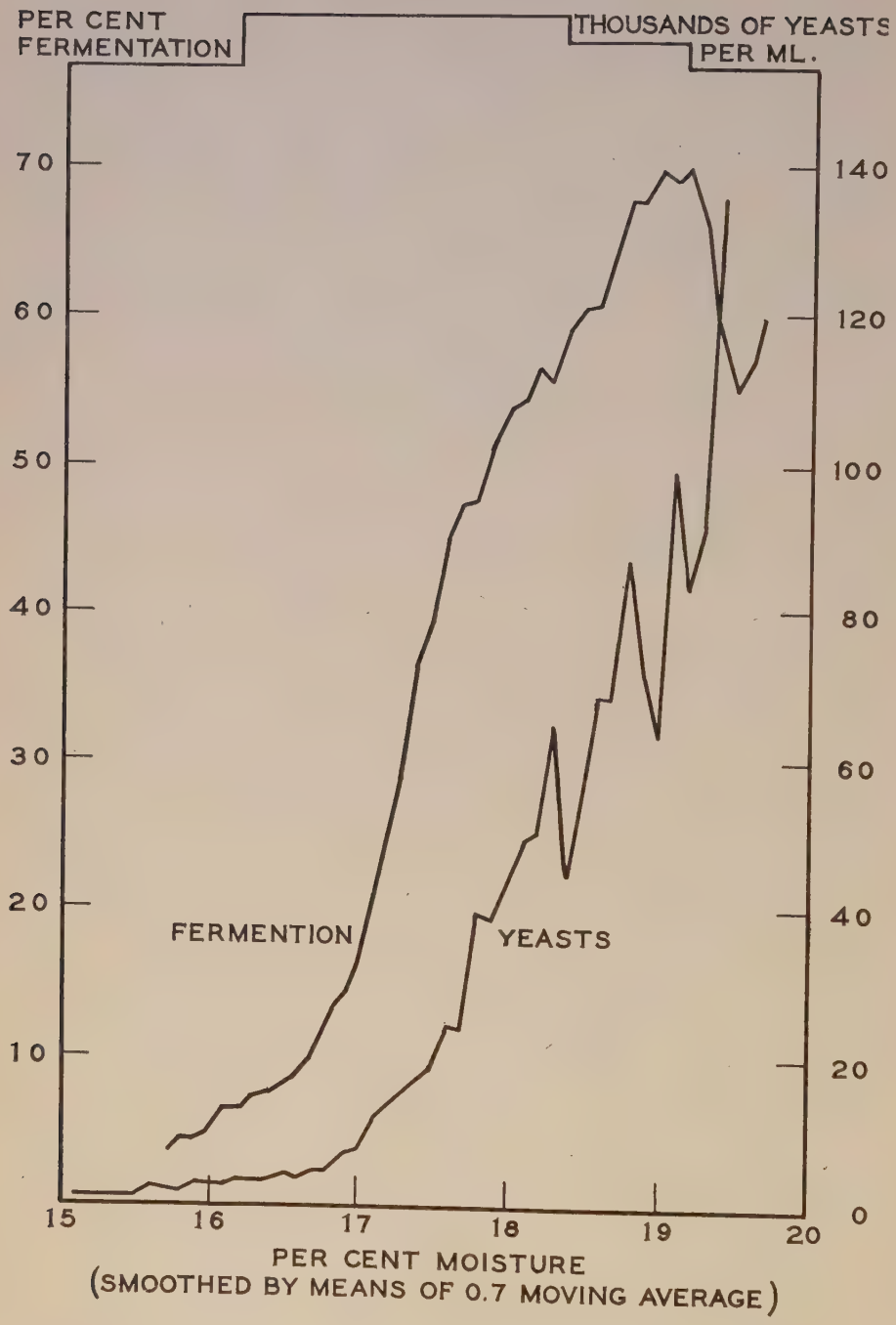

FIGURE 1. Relation of moisture content to yeast count and fermentation of Canadian honey.

TABLE 2.—DISTRIBUTION OF UNHEATED SAMPLES OF CANADIAN HONEY ACCORDING TO GRADE FOR SIX CROPS

Grade	Samples	1929	1931	1935	1936	1937	1938	All years
I	No. of samples	158	102	69	146	111	144	730
	No. fermented	23	20	6	5	20	37	111
	% fermented	14.6	19.6	8.7	3.4	18.0	25.7	15.2
II	No. of samples	14	18	24	9	25	15	105
	No. fermented	7	16	10	1	12	13	59
	% fermented	50.0	88.9	41.7	11.1	48.0	86.7	56.2
III	No. of samples	5	4	15	16	21	5	66
	No. fermented	2	3	9	11	14	5	44
	% fermented	40.0	75.0	60.0	68.8	66.7	100.0	66.7
Out	No. of samples	4	1	1	2	3	0	11
	No. fermented	4	1	1	2	3	0	11
	% fermented	100.0	100.0	100.0	100.0	100.0	—	100.0

TABLE 3.—FREQUENCY DISTRIBUTION OF UNHEATED SAMPLES OF CANADIAN HONEY ACCORDING TO MOISTURE CONTENT AND YEAST COUNTS

Moisture	Samples	Yeast count							Totals
		0.1 – 1.0	1.1 – 10	11 – 100	101 – 1000	1001 – 10000	10001 – 100,000	100,001 – 1,000,000	
%									
14.1–15.0	No. of samples	14	16	10	9	3	0	0	52
	No. fermented	0	0	0	0	0	0	0	0
	% fermented	–	–	–	–	–	–	–	–
15.1–16.0	No. of samples	31	17	38	42	26	4	0	158
	No. fermented	1	0	2	0	1	1	0	5
	% fermented	3.2	–	5.3	–	3.8	25.0	–	3.2
16.1–17.0	No. of samples	20	11	30	74	82	21	0	238
	No. fermented	0	1	1	9	10	1	0	22
	% fermented	–	9.1	3.3	12.2	12.2	4.8	–	9.2
17.1–18.0	No. of samples	12	5	19	35	58	55	9	193
	No. fermented	3	1	5	10	24	29	6	78
	% fermented	25.0	20.0	26.3	28.6	41.4	52.7	66.7	40.4
18.1–19.0	No. of samples	5	2	3	11	18	23	11	73
	No. fermented	0	2	3	6	13	15	10	49
	% fermented	–	100.0	100.0	54.5	72.2	65.2	90.9	67.1
19.1–20.0	No. of samples	1	0	0	1	5	8	7	22
	No. fermented	0	0	0	0	4	5	5	14
	% fermented	–	–	–	–	80.0	62.5	71.4	63.6
Entire range	No. of samples	83	51	100	172	192	111	27	736
	No. fermented	4	4	11	25	52	51	21	168
	% fermented	4.8	7.8	11.0	14.5	27.1	45.9	77.8	22.8

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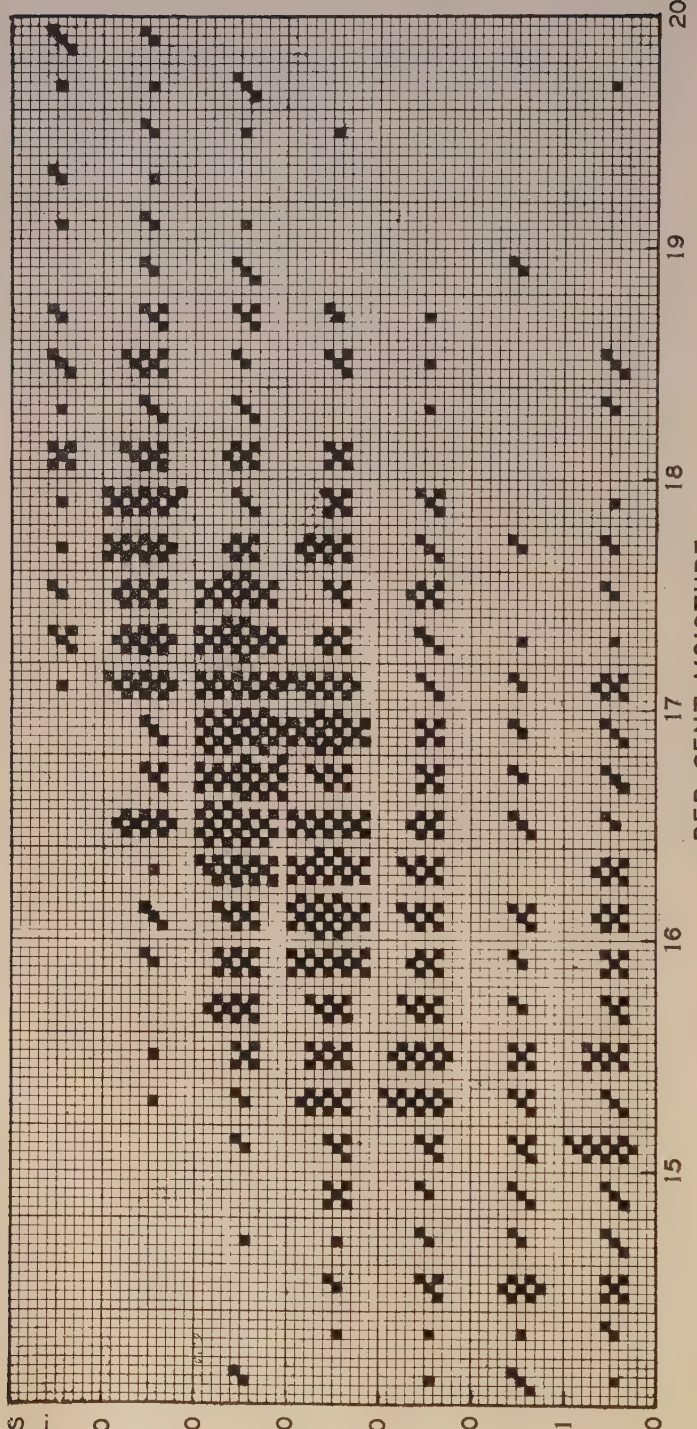

FIGURE 2. Yeast count of Canadian honey according to moisture content.

These tables show that approximately one-quarter of all the samples received fermented within the year and that in general the percentage of honey fermenting increases with increased moisture.

The reason fermentation does not occur as readily beyond 19.0% is explained by the fact that honey of higher moisture content crystallizes more slowly. The granulation of honey containing less than this amount of moisture has been observed to favour fermentation because of the moisture liberated when the dextrose forms crystals.

Moisture Content and Yeast Count

Table 3 presents the frequency distribution of 736 samples of the same honey arranged with class intervals of 1.0 logarithmic unit for yeast count and 1.0% for moisture. It has been necessary to decrease the number of samples dealt with in this section because of the uncertainty of the effect of heating the honey, to which earlier reference was made.

It is quite apparent that there is a definite relationship between moisture content and yeast count as indicated by the decidedly significant correlation of +0.50. Yeast count is plotted against moisture content in Figure 1. Higher moisture content, within limits, favours yeast multiplication and is therefore a potent factor in determining the number of yeasts in the honey, but other factors influence yeast counts also. This is obvious in Figure 2 which is a graphic presentation of data presented in Table 3.

On the basis of the data at hand for each increase of 1% moisture there is a corresponding increase of 4.81 times the original number of yeasts. The relation between yeast count and moisture may be expressed thus:— $\log Y = 0.6823X - 8.8562$, and by means of this equation Table 4 has been prepared. The lowest class was established by the mean yeast count found in honeys of 14.1 to 15.0%.

Table 4.—Predicted yeast count according to percentage moisture in honey

Moisture	Yeast count	Moisture	Yeast count
%		%	
15	24	18	2,600
16	115	19	12,800
17	550	20	62,000

The predicted values in Table 4 are based upon the geometric means of the classes involved, whereas those indicated in Figure 1 are based upon the arithmetic means of the same classes. The distribution of yeast counts for any given moisture content is decidedly skew, so that the arithmetic means are greatly affected by a small number of very large counts.

SUMMARY AND CONCLUSIONS

A study on the relationship of moisture content to fermentation and yeast count has been carried out on over 700 samples of Canadian honey. Under laboratory storage conditions about 25% fermented within the year. Increase in fermentation of samples was greatest in honeys of 17 to 18% of moisture.

For each increase of 1% in moisture content yeast count may be expected to increase about 5-fold. Rate of increase in yeasts, in general, parallels rate of increase in fermentation.

Both yeast count and fermentation are influenced by the length of time which honey takes to granulate. Above 19% of moisture honey may not granulate as readily, thus influencing yeast growth and consequent fermentation.

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A COMPARATIVE STUDY OF CERTAIN PERFORMANCE AND CARCASS CHARACTERISTICS OF YORKSHIRE BARROWS AND GILTS[1]

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Investigators have reported that sex has an influence upon the performance and the carcass characteristics of swine. Lush (3) analyzed records from the swine testing stations in Denmark. He found that sex had an important influence on thickness of belly and thickness of back fat. He also discovered that sex had a significant influence on body length but found no significant sex difference in daily gains.

Crampton and Ashton (2) found a highly significant difference in rate of gain between the sexes. In feeding trials they found that male pigs gained 10 to 15% faster than females. Males required, on the average, a feeding period 14 days shorter than the females. They also found the carcasses of the females to be longer, to possess less fat over the shoulder and back, to have less thickness of belly, a larger eye of lean, and a higher percentage of lean in the rasher than did the carcasses of the males. They concluded from their study that, irrespective of ration fed, female carcasses graded higher, on the basis of present grade standards, than male carcasses.

Correlation coefficients for various carcass characteristics have been calculated by numerous workers. In nearly all cases, however, the computations have not been done separately for male and female carcasses. Nevertheless, the relationships which were found to exist are of interest.

Sinclair and Murray (6) found that there was no significant correlation between length of body and depth of back fat nor between body length and percentage shoulder. Lush (3) reported a strong negative correlation between body length and thickness of back fat. Stothart (8) found no significant relation between length of carcass and thickness of shoulder fat. He did find a significant negative correlation between length of body and area of loin muscle, and, also, between area of loin and thickness of shoulder fat.

Crampton (1) reported that rate of gain was not related to length of side nor to leanness of carcass. He also stated that length was not correlated with leanness. Crampton and Ashton (2) found that there was a significant correlation between gains and area of loin. They found that pigs that are older at time of slaughter have a larger area of loin.

The objective of this study was to obtain information that would be of some assistance in the interpreting of performance and carcass data of swine and particularly of swine of the Yorkshire breed.

MATERIALS AND METHODS

All data, from which the analyses reported in this paper were made, were obtained from the records of test groups of pure-bred Yorkshire swine that completed tests between May 1942 and February 1945 at the Advanced

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Registry Test Station at Saskatoon, Saskatchewan. Those animals in which sickness or disease had evidently retarded growth rate were not included in the analyses.

The pigs on which the study was conducted were handled according to the advanced registry testing plan. Full details of this plan, as well as the method of cutting and measuring the carcasses, are explained by Peterson (4) and by the Production Service, Department of Agriculture, Ottawa, Canada (5). The same operator was in charge at the Station throughout the observed period. Standard rations were fed and it is felt that environmental conditions were sufficiently constant to make unnecessary any adjustment for seasons, years, or rations.

It was originally thought that there would be a sufficient number of test groups made up of two males and two females for studies to be made on a paired basis. However, this was not the case. Only 37% of the groups that finished tests were actually made up of two males and two females, while 19% of the groups were made up of four pigs of similar sex. The information was, therefore, grouped according to sex and analyses made on a group comparison basis, according to the method outlined by Snedecor (7), rather than on an individual paired basis.

Simple correlation coefficients for certain performance and various carcass characteristics were calculated following the method outlined by Snedecor (7).

A total of 220 males and 181 females are included in that part of the study dealing with 70-day weights and daily rate of gains. In the carcass studies only those animals that were slaughtered within the live weight range of 198 to 207 pounds, inclusive, were used. This reduced the numbers in the carcass studies to 154 males and to 127 females.

RESULTS

Performance and carcass characteristics

The results of the study of certain performance and carcass characteristics are given in Table 1.

Male pigs were not significantly heavier than female pigs at 70 days of age. The larger daily rate of gain for males was, however, highly significant. Males attained a live weight of 200 pounds 4.34 days earlier than females, but this difference was just slightly under the level of significance.

Highly significant sex differences were found for all the carcass characteristics studied except for the difference in fat thickness. The difference in fat thickness is a measure of uniformity of the thickness of fat along the back. This difference is obtained by subtracting the minimum fat measurement, which was always over the back in the carcasses studied, from the maximum fat measurement, which was always over the shoulder. The carcasses from females did not have as great a thickness of fat as the male carcasses but the fat layer was just as uniform on the females as on the males.

Female carcasses were longer, heavier in the shoulder, lighter in percentage of middle, and heavier in the ham than were the male carcasses. Both males and females were much too heavy in shoulder, too light in

TABLE 1.—SUMMARY OF CERTAIN CHARACTERISTICS OF YORKSHIRE BARROWS AND GILTS

Characteristic	Mean Values		Pooled sums of squares	Difference in means	Standard error of difference in means	*t* value
	Male	Female				
70-day weight[1]	37.886 lb.	37.359 lb.	21,993.819	.527	.745	.707
Daily rate of gain[1]	1.280 lb.	1.234 lb.	9.5649	.046	.015	3.067‡
Age at 200 lb. live weight	198.10 days	202.44 days	94,657.8	4.340	2.207	1.966
Length of side	30.997 in.	31.338 in.	189.35	.341	.098	3.480‡
Thickness of shoulder fat	1.969 in.	1.798 in.	12.63	.171	.024	7.125‡
Thickness of back fat	1.101 in.	0.954 in.	9.13	.147	.022	6.682‡
Thickness of loin fat	1.529 in.	1.404 in.	12.17	.125	.025	5.000‡
Difference in fat thickness (shoulder fat—back fat)	.873 in.	.850 in.	10.46	.023	.023	1.000
Percentage shoulder	27.228	27.646	266.27	.418	.117	3.573‡
Percentage middles	48.750	47.830	540.11	.920	.166	5.542‡
Percentage hams	24.028	24.506	205.38	.478	.102	4.686‡
Area of loin	5.092 sq.in.	5.870 sq.in.	227.62	.778	.110	7.073‡
Total carcass score	76.448%	80.071%	25,039.00	3.623	1.135	3.192‡

[1] Degrees of freedom = 399. For all other items the degrees of freedom = 279.
‡ Significant at the 1% level of probability.

middle, and a little too light in ham to attain top bacon-type score. In balance of side, the males had a slight advantage over the females in scoring in that their lighter shoulders and heavier middles more than offset the larger hams possessed by the females. In no instance was there a carcass found which possessed the ideal balance of side, viz., 50% middles, 25% shoulder, and 25% ham.

The gilts possessed a very distinct and valuable advantage over the barrows in that the area of loin was larger. This, along with less thickness of fat on shoulder, back and loin, was largely responsible for the female carcasses scoring higher than did the male carcasses. This difference in carcass score in favour of females is similar, though not as large, as that found by Crampton and Ashton (2).

CORRELATION STUDIES

Simple correlation values were calculated for various characteristics. These values are shown in Table 2. Multiple correlations for these same characters were not calculated. No measure of the effect that inter-correlation or that the inter-dependence of the many characters would have on the apparent simple correlations was, therefore, obtained.

The weight at 70 days of age was positively and significantly correlated to the rate of daily gain for both males and females. This would suggest that the same factors, which are responsible for pigs attaining a large size at 10 weeks of age, continue to have an influence during the later life of the pig and until market weight is attained.

Both males and females showed highly significant negative correlations between length of side and thickness of shoulder fat. This finding agrees with the results published by Lush (3) but disagrees with the findings of Stothart (8), and Sinclair and Murray (6).

TABLE 2.—SIMPLE CORRELATION VALUES FOR VARIOUS CHARACTERISTICS OF BARROWS AND GILTS

Characteristic	Sex	Daily rate of gain[1]	Age at 200 lb. live weight	Thickness of shoulder fat	Percentage shoulder	Percentage ham	Area of loin
70-day weight[1]	Male	+.317†	—	—	—	—	—
	Female	+.161*	—	—	—	—	—
Length of side	Male	—	+.365†	−.456†	+.213†	—	+.085
	Female	—	−.108	−.231†	+.072	—	−.021
Age at 200 lb. live weight	Male	—	—	+.106	−.043	—	+.041
	Female	—	—	−.012	+.264†	—	−.014
Percentage middle	Male	—	—	—	+.259†	−.752†	—
	Female	—	—	—	−.476†	−.677†	—
Percentage shoulder	Male	—	—	−.079	—	—	—
	Female	—	—	−.397†	—	—	—
Thickness of shoulder fat	Male	—	—	—	—	—	−.047
	Female	—	—	—	—	—	+.018

[1] Degrees of freedom = 218 for males and 179 for females. For all other items degrees of freedom = 152 for males and 125 for females.

* Significant at the 5% level of probability.

† Significant at the 1% level of probability.

Barrows showed a positive significant correlation between percentage middle and percentage shoulder, while the gilts showed a negative and significant correlation between these characteristics. There was a fairly large and highly significant negative correlation between the percentage middle and the prcentage ham for both barrows and gilts. This would indicate that the desired balance of side will be difficult, if not impossible, to attain. As stated in the discussion following Table 1 of this paper, males and females were both lower in percentage middle and percentage hams than the level considered as the optimum percentage for these characteristics with ideal bacon type. Then, if the percentage ham regularly decreases as the percentage middle increases, it would appear to be impossible to achieve the desired percentages for these parts.

A significant negative correlation between percentage shoulder and thickness of shoulder fat and a significant positive relation between age at 200 pounds, live weight, and percentage shoulder was found among the females. No significant relationship was found among the males for these same respective characteristics.

The males showed a significant positive relationship between length and age at 200 pounds, live weight, and also for length and percentage shoulder while no significant relationship between these respective measurements was found among the females.

No significant simple correlations were found between area of loin and length of side, area of loin and age at 200 pounds live weight, area of loin and thickness of shoulder fat for either the males or females.

DISCUSSION AND CONCLUSIONS

The results of this study show rather conclusively that there is a considerable difference in the performance and carcass characteristics of Yorkshire barrows and gilts. Male pigs gain in weight faster than female pigs, and females attain a higher carcass score than do the males when both are scored according to the advanced registry scoring system. These differences are sufficiently large that it appears necessary, when testing litters to determine heredity differences, to have both males and females in the test group. If four animals are to comprise the test group it would appear desirable to have this group made up of two males and two females. When it is not possible to have both sexes equally represented, some adjustment for sex should be made.

The data also demonstrate that the weight at 70 days of age is an important item in determining later performance of both males and females. The larger pigs at 70 days of age will attain a live weight of 200 pounds before the smaller pigs because of two factors. In the first place they have a larger initial weight and do not need to gain as many pounds to reach the 200 pound weight. The second factor is that the heavier pigs have a higher daily rate of gain, on the average, than do the lighter pigs during the period from 70 days of age and up until market weight is reached. The influence of the 70-day weight is sufficiently important to make it necessary that the test animals from a litter be truly representative of the litter according to the 70-day weights of the individuals in the litter. If the test group from one litter were too heavy to truly represent the litter, while the test group from a second litter were too light to truly represent the 70-day weight of the litter, a bias would be introduced and the difference in heredity of the two litters would not be accurately compared.

The study also demonstrates that Yorkshire barrows and gilts, as represented by the animals used in this study, fall short of the ideal in balance of side. They were too light in middle and ham and too heavy in shoulder. Not a single individual was found that possessed the ideal balance of side. The results show, also, that the percentage ham decreases as the percentage middle increases. It would, therefore, appear to be impossible to attain the ideal balance of side through a system of selective breeding among Yorkshires such as those included in this study.

SUMMARY

Performance records of 220 male and 181 female, and carcass data on 154 male and 127 female Yorkshire pigs that completed tests under the advanced registry plan were analyzed.

There was no significant difference in 70-day weight between barrows and gilts but barrows had a significantly larger daily rate of gain.

Significant sex differences were found for nearly all carcass characteristics. Carcasses from females were longer, heavier in shoulder, lighter in middle, heavier in ham, and larger in area of loin muscle than were the carcasses from males. Both males and females were too heavy in the shoulder and too light in middle and ham for optimum bacon-type score.

Simple correlation values were calculated for various characteristics. A significant positive correlation between 70-day weight and daily rate of gain, a significant negative correlation between length of side and thickness of shoulder fat, and a rather large and significant negative correlation between percentage middle and percentage ham was found to exist for both barrows and gilts.

Sex differences in correlations were found for some characteristics. Males showed a positive correlation for some characteristics while females showed a negative correlation for these same factors. In other cases females showed a positive correlation for certain factors and males showed negative correlations for the same items.

It was concluded that sex differences in performance and carcass characteristics are sufficiently great to make it desirable to have small test groups of Yorkshire swine made up of equal numbers of males and females. It was also decided that, because of the influence the 70-day weight had upon later performance, the 70-day weights of the individuals in the test group should be truly representative of the 70-day weights of the individuals in the whole litter when it is desired to measure heredity differences of litters.

It was concluded, also, that it would be very difficult, if not impossible to attain the present ideal balance of side through a system of selective breeding among Yorkshire swine similar to the animals studied.

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TATTOO IDENTIFICATION OF SHEEP AND HORSES[1]

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A report (1) was published in 1940 on an investigation of certain phases of live stock tattooing. The majority of the large number of test animals of different species used in the investigation are no longer available for examination. However, a large proportion of experimentally marked sheep and horses remain and these have been inspected recently.

Since the trial period involved is a lengthy one and not easily duplicated, the information is reported here. The data, more especially with respect to sheep, are conclusive, and a practical application should benefit those breeders who have had unsatisfactory results in tattoo identification.

While the data obtained are from tests on two breeds of sheep and one breed of horses, it is considered that parallel results can be expected in other breeds and species.

SHEEP TATTOOING

In some breeds of sheep ear tattooing with black ink has not always provided permanent identification. Breeders have noted that, while a high proportion of animals of one breed retain a legible tattoo for long periods, other sheep which have been tattooed in the same manner may be very difficult to identify. In many cases tattoos become completely illegible which tends to discourage tattooing.

The causes, aside from the use of low grade materials or poor workmanship, appear to be due either to a thickening of the ear tissue or to naturally occurring darkly pigmented areas. In the latter case the dark patches of skin may be quite small at the time of tattooing but enlarge with maturity and, especially in older tattoos, make deciphering of tattoo symbols difficult.

Coloured Tattoos

To overcome these difficulties coloured tattoo compounds were formulated and tested on small groups of Southdown and Shropshire sheep. Two of these, which contained organic dyestuffs, proved to be non-toxic in a seven-month trial and showed a high colour retention. The ease of reading and high percentage legibility exhibited were so superior to black tattoos that tests on a larger scale were commenced.

After two years, the superiority of blue and green tattoos in both flocks was maintained. There was no apparent loss of colour intensity and all tattoos could be easily deciphered.

In the Shropshire flock, after five years, over 50% of the test sheep remained and these were given a final inspection. The reading of the coloured tattoos gave no difficulty. No diminution of colour had occurred since the original application and it was quite apparent that these tattoos would continue to be legible for the life of the animals. Neither special cleaning of the tattooed surface nor transmitted light were required.

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Comparison of Black and Coloured Tattoos

To illustrate the contrast between these results and previously observed black tattoos in the same flock, the data are summarized in Table 1.

Table 1.—Percentage legibility of Shropshire tattoos

Age of Tattoo	Black				Blue and Green	
	No. of tattoos	Legibility			No. of tattoos	Legibility—no treatment
		Before cleaning	After cleaning*	Transmitted light‡		
years		%	%	%		%
1	24 (12)	96	96	96	38 (19)	100
2	39 (20)	56	66	74	36 (18)	100
3	4 (2)	50	50	50		
4	24 (12)	50	66	66		
5	22 (11)	17	17	22	26 (13)	100
6	6 (3)	0	0	16		
7	2 (1)	0	0	0		
8	2 (1)	0	0	0		

* Ear surface cleaned by cloth dampened with carbon tetrachloride.
‡ Pen light behind and against tattooed area.
Note: The number of sheep examined at each period is indicated in brackets.

This comparison indicates that either green or blue tattoo compounds are more reliable than black. In addition the readability is enhanced.

These tests are considered to be conclusive in establishing coloured compounds as satisfactory tattooing mediums for the permanent identification of Southdown and Shropshire sheep. No other tests of these new tattoo formulas have been conducted but it would appear that they may have a wider application, not only in other breeds of sheep, but in other species of animals where colour contrast is desirable.

HORSE TATTOOING

Attempts to develop a tattooing technique that would provide positive identification and that would be applicable to all breeds of horses were commenced six years ago. While the trials were confined to the Clydesdale breed, it is considered that the results obtained may be applicable to many other breeds.

Due to circumstances, the number of animals on trial was less than desired for a test of this nature, but evidence has been obtained to show that horses, like other animals, may be individually identified by tattoo.

In approaching the problem many factors had to be considered, such as method of application, size of tattoo pliers and shape of needles, pigment concentration and viscosity, and optimum location for tattoo. A sufficiently long period has now elapsed to permit an assessment of the various factors involved. The conclusion has been reached that, with some modifications, the technique of tattooing used can be offered as a practical method for horse identification.

Tattoo Location

The area chosen for marking was inside of the lower lip, a location which offered a good contrast to black pigment. Healing takes place quickly here and there are the additional advantages of ease of application and inspection. Lip tattooing in the test horses caused no disfigurement and no apparent disturbance of feeding habits.

Since the mucous lining of a horse's mouth differs from skin structure previous observations on skin punctures would not necessarily apply. Hence the most effective shape and spacing of tattoo needles were investigated as well as the effect of depth of penetration. It was found that moderately shallow punctures are to be preferred. Penetration was controlled by the thickness of stripping pad used. Pointed needles are preferred to those with chisel shapes.

To counteract the expected interference due to excessive saliva, astringents and quick setting protective layers were tested. The former were used, both when incorporated in the formula and applied to the freshly made tattoo. However neither of these expedients was found to be a requirement.

Pigment Mixture

One of the most important factors in tattooing is the pigment mixture. It must have a sufficiently high concentration of pigment to ensure legibility and at the same time possess sufficient penetrating power. In addition the setting time of the compound must be such that, once applied, it will set quickly but not fast enough to interfere with handling operations. The best medium was found to be a black paste of about the same consistency as thick paint.

Tattooing Technique

The tattooing operation adopted is relatively simple and gives no particular difficulty in practice. Two persons are required. The horse is placed behind a wall or gate of convenient height and a twitch is applied to the upper lip.

The dies are placed in the pliers and tested for correctness by trying on a piece of paper. A rubber stripping pad is pressed down over the needles. An area on either side of the lip is wiped free of saliva and the tattoo compound placed on the dry area and on the tattoo needles. The tattoo is now made, very moderate pressure being required. The suggested location is approximately one inch from the lip margin.

With the lip held down a further quantity of compound is applied and rubbed well into the punctures. The lip is held down for a further fifteen seconds, to ensure setting of the compound.

The test group of horses did not include foals but experience in tattooing other animals shows that a young animal is a better subject for tattooing both from the point of view of management and results. Of the twelve horses remaining from the original group, eight had legible tattoos after a six-year period. The tattoos were viewed in daylight and legibility judged under those conditions, although it is known that doubtful tattoos can usually be deciphered by using transmitted light.

Observations made at the end of the test period indicate that astringents and protective coatings on the tattoo are not necessary. Since no deterioration in legibility occurred, it can be assumed that identification will be maintained for a further long period.

Modified pliers, having a deeper throat than the conventional type, would assist in a careful placement of the tattoo.

CONCLUSIONS

Coloured tattoos are permanent, more easily read and more reliable than black tattoos, in Southdown and Shropshire sheep.

Green and blue tattooing compounds are equally effective in the above breeds and are non-toxic.

Lip tattooing of horses requires:—

1. Concentrated paste form of tattoo compound.
2. Closely spaced, relatively short and pointed needles.
3. Attention to correct technique.

The individual identification of Clydesdale horses has been demonstrated. Lip tattooing is believed to be suitable for use on other breeds.

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PHOSPHORUS FIXATION STUDIES WITH SOME SASKATCHEWAN SOILS

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As is commonly known a considerable proportion of the phosphorus contained in fertilizers undergoes chemical change in the soil whereby the phosphorus is rendered relatively insoluble and unavailable to plants. This alteration of available phosphorus to unavailable forms is known as phosphorus fixation and constitutes one of the major problems in the use of phosphatic fertilizers. The extent to which fixation occurs varies considerably depending on the physical and chemical properties of the soil. No studies of the losses due to phosphorus fixation have been made with Saskatchewan soils but considering their great variations in physical and chemical properties it can be expected that there will be an equally large variation in their ability to fix phosphorus. Information concerning phosphorus fixation in Saskatchewan soils is needed in order to ascertain the fertilizer needs of the various soil associations and for the development of a sound program for fertilizer use.

The present study was undertaken to obtain information on the following points: (1) the rate and extent of phosphorus fixation in some typical Saskatchewan soils; (2) the effect of type of fertilizer used on the rate of phosphorus fixation; (3) the accumulation of nitrates as affected by soil type, addition of phosphate, and the presence of added nitrogen contained in the ammonium phosphate applied.

LITERATURE

The term phosphorus fixation has been used with different meanings. For the purpose of this study phosphorus fixation will be considered as a change of available phosphorus to a form not extracted by Truog's (23) solution as modified by Doughty (3). Truog (24) considers this to be a fair measure of the amount of phosphorus available to the plant. The phosphorus which is not extracted by this solution is considered to be in a difficultly available form.

The literature on the various aspects of phosphorus fixation is very extensive. A large number of papers deal with the various mechanisms of fixation and the various factors affecting fixation. These are best summarized in the reviews presented by Midgley (14) and Murphy (17).

Phosphorus fixation may occur by a number of different processes, depending largely on the pH of the soil. Chemical precipitation is the most important mechanism of fixation in calcareous soils, the soluble phosphates being precipitated as insoluble calcium and magnesium phosphates. McGeorge (10) states that in the presence of free lime a large part of these phosphates are converted to the carbonato-phosphate form which, due to its high potential alkalinity, is not readily rendered soluble by the action of plant roots. In acid soils phosphorus is fixed by chemical precipitation, mutual precipitation and by adsorption. Chemical precipitation is the result of ions of iron and aluminum combining with phosphate ions in

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solution forming insoluble compounds which are precipitated. However, Murphy (17) has pointed out that the soil solution is very dilute with respect to iron and aluminum ions and therefore contends that chemical precipitation of phosphorus from solution is negligible except in extremely acid soils. According to Metzger (13) mutual precipitation is one of the most important types of phosphorus fixation. This mechanism involves the precipitation of soluble phosphate on the colloidal surfaces of iron and aluminum hydrogels in the soil. Murphy (17) attributes a large portion of fixation to adsorption. The phosphate ions displace $SiO_3^{=}$ and OH^{-} ions from the crystal surfaces and become fixed in a form difficultly available to plants.

FACTORS AFFECTING FIXATION

Of the numerous soil properties that affect the extent and mechanism of phosphorus fixation, soil reaction is probably the most important. Murphy (17) has shown that maximum fixation due to chemical precipitation caused by iron and aluminum ions in solution occurs below pH 5.0. Scarseth (20) has shown that mutual precipitation is greatest at pH 3.7 with a slight decrease at pH 3.3 and a rapid decline above pH 5.5. He found increasing fixation by adsorption from pH 5.0 to 6.5 followed by a decline until no phosphorus was fixed at pH 7.5. At pH's above 6.5 phosphates become increasingly insoluble in the presence of calcium by forming tri-calcium phosphate or the more insoluble carbonato-phosphate.

The effect of $SiO_2 : R_2O_3$ ratio on phosphorus fixations has been studied by a number of workers. Scarseth (20) and Murphy (17) have concluded that with decreasing $SiO_2 : R_2O_3$ ratio there is usually increased fixation of phosphorus.

The effect of the degree of base saturation on a soil's capacity to fix phosphorus has been studied by Heck (6). By increasing the amount of exchangeable bases to give 90% base saturation he substantially reduced the amount of phosphorus fixation. He also found that increased base exchange capacity tends to decrease phosphorus fixation provided that the proper degree of base saturation is maintained. Heck's (6) data indicates that the degree of base saturation giving minimum fixation will be obtained at a lower pH if the organic matter content of the soil is high. It follows then, that soils of high organic matter content will fix less phosphorus than a similar soil of low organic matter content. Dunn (4) suggests that organic matter reduces phosphorus fixation by coating the mineral surfaces concerned thus preventing fixation, while Mattson (12) suggests that humate ions may displace adsorbed phosphorus from mineral surfaces. In any case it may be concluded that organic matter is effective in reducing the amount of fixation even though the reason for this is not definitely known. McGeorge (10) states that in calcareous soils organic matter is important in maintaining a supply of available phosphorus. He attributes this to the solvent action of carbonic acid which results from organic matter decomposition.

Physical conditions that affect chemical equilibrium also have an influence on phosphorus fixation. Time is an important factor; Heck (5) found that the period required for fixation under field conditions ranged from one month to a year. Robinson (18) showed that the rate of fixation increased with temperature, but this has little practical significance. The

effect of the soil-water ratio is more important. Hibbard (8) states that, in the field, from several months to a year may be required to fix phosphorus from applied fertilizer in clay soils. In a 1 to 1 soil-water mixture he obtained maximum fixation within an hour.

Hibbard (8) attempted to show the effect of different phosphate salts on fixation but his results are not conclusive. However, his work indicates the desirability of determining whether or not different phosphate fertilizers have different fixation rates when under the same conditions.

Although the causes of phosphorus fixation are now fairly well understood, the minimization of fixation in the soil is still a major problem. Some progress has been made in reducing fixation by the use of improved fertilizers and by better cultural practices. Many present day manufacturing processes granulate fertilizers in a form, which, it is hoped, will reduce the rate of phosphorus fixation. Hockensmith *et al.* (9) found that favourable placement of fertilizers greatly increased adsorption of phosphorus by plants. Liming and incorporation of organic matter into the soil are cultural practices which have been found to reduce phosphorus fixation. Spencer and Stewart (22) showed that some organic phosphates were not fixed by the soil. Such compounds eliminate loss of applied phosphate and fertilizers of this type may eventually be generally available.

METHODS AND MATERIALS

This project has been divided into two phases, the first consisting of laboratory studies and the second consisting of greenhouse studies.

Soils Used

The four soils selected for this study are similar in parent material. The Lloydminster, Oxbow, and Yorkton soils are from the black soil zone and differ mainly in reaction of their surface horizons. The Loon River soil is from the grey (podzolic) soil zone and was selected as a representative of the podzolic soils of the north-west portion of Saskatchewan.

The Lloydminster Association is not extensive in Saskatchewan but covers a considerable area in Alberta. These soils have a deep black solonetzic profile, and are developed on dark resorted boulder clay with a moderate lime content.

The Yorkton Association is extensive in Saskatchewan, occupying an area of almost two million acres. This soil usually has a deep black high lime profile only weakly developed and often containing calcium carbonate to the surface. The parent material is a calcareous resorted boulder clay.

The Oxbow Association is the most extensive one in the black soil zone occupying an area approaching seven million acres. This association is fully described by Mitchell *et al.* (15). The hard columnar profile is most common although solonetz and calcareous earth member profiles occur. The profiles are usually well developed, having a moderately black surface horizon, a hard columnar B horizon and a distinct lime layer. The parent material consists of undifferentiated calcareous boulder clay.

The Loon River Association constitutes a considerable area of the grey podzolic soils of north-western Saskatchewan. It is a deep podzolic soil developed on glacial till which is heavy sandy clay in texture and which has

very little free lime. The surface horizon has an A_0–A_1 layer $\frac{1}{2}''$–$2''$ thick, while the A_2 is ashy grey and deeply leached. The B horizon is darker in colour and of hard columnar structure. No definite lime layer is found.

Laboratory Experiment

In the laboratory an incubation experiment was set up to determine the rate of phosphorus fixation in four soils and to ascertain the effect of the nitrogen carried by some of the fertilizers on the rate and extent of phosphorus fixation.

The soils used in this experiment were first dried and then ground to pass a 20-mesh sieve. The various fertilizers, after being pulverized, were added to the four soils at a rate equivalent to 50 p.p.m. of elemental phosphorus. After thorough mixing, ten samples of seventy grams were taken from each of the various treatments and placed in small sample bottles.

Duplicate samples of each of the different treatments were then set aside without incubation. The remaining samples were incubated at room temperature for varying periods. The incubation consisted of moistening the soils to approximately field moisture content, and maintaining them at this moisture level for the required incubation period. Duplicate samples were withdrawn from incubation after 3, 6, 9, and 24 weeks, dried and ground to pass a 100-mesh sieve. A portion of this material was then used in the determination of available phosphorus. The extent of phosphorus fixation for the different treatments and times was taken to be the difference between the amount of available phosphorus in the incubated sample and the amount in the non-incubated sample.

For the laboratory study four soils were used in conjunction with four different fertilizer treatments. The soils used were surface samples taken from summerfallow fields to the depth of five inches and were members of the Lloydminster, Yorkton, Oxbow and Loon River Soil Associations. The first three of these soils were selected because of their widely different reactions; the Loon River soil was selected for its low organic matter content and high $SiO_2 : R_2O_3$ ratio.

Fertilizers used in both greenhouse and laboratory studies were 11–48–0, 16–20–0, 0–38–0 and 0–38–0 plus NH_4NO_3. The 0–38–0 plus NH_4NO_3 fertilizer was prepared by blending pulverized 0–38–0 with sufficient ammonium nitrate to give the same ratio of phosphorus to nitrogen as is contained in 11–48–0. This has been designated in the tables as P–NO_3. All fertilizers were ground to pass a 100-mesh sieve to insure uniformity when they were mixed with the soil; this would insure maximum fixation under the conditions of the experiment.

Greenhouse Experiment

A greenhouse experiment using gallon crocks was set up having the same fertilizer treatments as were used in the laboratory experiment. Soils of the Lloydminster, Yorkton and Oxbow Associations were used in this experiment. The incubation periods were 0, 3, 6 and 9 weeks and were started at 3-week intervals, all being completed at the same time. After incubation, samples were taken for the determination of available phos-

phorus and prepared in the same manner as described for the laboratory incubation experiment. That portion of the samples not used for the determination of available phosphorus was retained for the determination of nitrates. Each crock contained enough soil to fill four shallow 6″ pots. These pots were sown to pre-germinated barley which was then grown for seven weeks. Distilled water was used to water the plants in order to avoid change in soil reaction due to the alkalinity of the tap water. The crop was cut in the shot-blade stage, dried and weighed. This weight was taken as a measure of the relative yielding ability of grain grown on the various treatments. The plant material was ground and analysed for phosphorus content in an attempt to correlate this with the supply of available phosphorus in the soil. After cropping, soil samples were again taken and prepared for the determination of available phosphorus.

Methods of Analysis

Available phosphate determinations were made using Truog's (23) solution as modified by Doughty (3). A photo electric colorimeter was used for phosphorus determinations according to the method described by Bertramson (1). Phosphorus fixing capacities of the four soils were determined by Heck's method (5). Phosphorus content of plant material was determined by the method of Shelton and Harper (21). Other chemical determinations were made by standard methods.

RESULTS AND DISCUSSION

Analytical Data for Soils Used

Results of chemical determinations made on the soils used in this study are given in Table 1. These data are closely related to the phosphorus problems of these soils.

As already mentioned the Oxbow, Lloydminster and Yorkton soils used in this study were selected because of the general similarity of their parent materials and because they differ widely in the reaction of their surface horizons. These soils from the black soil zone have $SiO_2 : R_2O_3$ ratios which are quite similar and which are considerably lower than the $SiO_2 : R_2O_3$ ratio for the podzolic Loon River soil. However, in the Loon

Table 1.—Analytical data for soils used
(cultivated surface horizon)

	Soil			
	Lloydminster	Oxbow	Yorkton	Loon River
pH	5.42	7.10	7.72	6.78
$SiO_2 : R_2O_3$ ratio	4.95	4.78	5.56	7.90
Organic matter, %	4.98	3.79	5.52	2.58
Total phosphorus, %	0.039	0.052	0.054	0.037
Available phosphorus, p.p.m.	24.8	50.0	63.2	18.8
Phosphorus fixing capacity, p.p.m.	105.2	55.5	23.1	18.0
Phosphorus fixed, p.p.m.	15.0	10.0	0	13.0
Total nitrogen, %	0.366	0.250	0.354	0.110
Nitrate nitrogen, p.p.m.	15.9	57.8	38.4	—

River soil the organic matter content is much lower than in the three black soils. The total phosphorus content of the Oxbow and Yorkton soils is lower than in similar Alberta soils while it is especially low in the Lloydminster and Loon River soils. It may be expected that the phosphorus rendered available by weathering in such soils will be less than in soils with a higher total phosphorus content. It is, therefore, probable that under cereal cropping the need for phosphatic fertilizers will be greater on soils such as these which have a low total phosphorus content than on soils with larger amounts of total phosphorus. The low content of available phosphorus in the Loon River and Lloydminster soils as compared with the Oxbow and Yorkton soils is probably a reflection of the differences in total phosphorus contents of the soils. The data for total phosphorus fixing capacity vary widely indicating very different properties in the soils concerned. However, these phosphorus fixing capacities are low when compared to some lateritic soils. Moser (16) has reported phosphorus fixing capacities as high as 400 p.p.m. The data for total nitrogen and nitrate nitrogen content indicate further differences in the soils concerned.

Laboratory Fixation Study

The amount of available phosphorus in each of the variously treated soils after the different periods of incubation is given in Table 2. The amount of added phosphorus fixed in an unavailable form can be calculated by subtracting the amount of phosphorus available after incubation from the amount available before incubation. The stability of the checks for

Table 2.—The influence of incubation period and kind of fertilizer on the amount of available phosphorus in four soils incubated in the laboratory

(Results expressed as p.p.m. available phosphorus)

Soil	Treatment	Incubation period				
		0 weeks	3 weeks	6 weeks	9 weeks	24 weeks
Lloydminster	Check	24.8	25.2	25.6	26.2	28.0
	11–48–0	65.5	49.6	50.2	49.4	50.0
	16–20–0	64.7	51.1	52.8	50.8	50.8
	T. S. P.	66.3	49.1	51.8	49.6	50.8
	P–NO_3	66.1	52.8	51.1	51.0	51.6
Oxbow	Check	50.0	50.2	52.8	53.0	53.2
	11–48–0	89.2	82.0	78.9	80.5	79.6
	16–20–0	89.2	79.2	79.8	80.3	80.5
	T. S. P.	90.7	79.9	79.6	80.4	81.0
	P–NO_3	88.2	79.9	78.3	78.4	79.3
Yorkton	Check	63.2	63.0	63.4	62.6	63.2
	11–48–0	99.8	99.4	100.6	100.7	101.0
	16–20–0	100.2	100.0	99.1	99.6	100.4
	T. S. P.	101.6	100.8	101.2	100.2	100.8
	P–NO_3	100.3	99.6	100.6	100.5	99.2
Loon River	Check	18.8	19.1	20.4	19.8	21.4
	11–48–0	57.1	44.1	44.0	43.4	43.3
	16–20–0	57.7	44.2	43.5	44.0	44.7
	T. S. P.	58.1	45.1	46.0	45.4	45.4
	P–NO_3	56.6	45.0	44.8	44.0	45.0

each soil over the 24 weeks of incubation shows that the soils, as taken from the field, were at equilibrium with respect to their content of available phosphorus. The slight increase in available phosphorus with incubation of the checks may be attributed to normal decomposition of organic matter and mineralization of phosphorus previously in organic form.

A sharp decline in the available phosphorus content of incubated soil is shown for all fertilized treatments on the Lloydminster and Loon River soils. This is true to a lesser extent on the Oxbow soil. The Lloydminster soil has fixed about 15 p.p.m. which is 30% of the applied phosphate. The Loon River soil fixed 13 p.p.m. while the Oxbow fixed 10 p.p.m., this being respectively 26 and 20% of the applied phosphate. The rapidity of fixation is rather notable; almost all of the fixation has occurred in the first three weeks with little change resulting from increased length of incubation period. This can probably be partly attributed to the intimate mixture of the fertilizer with the soil.

From the results of Table 2 it can be concluded that fixation of phosphorus in an acid insoluble form did not occur on the Yorkton soil. However, phosphorus may have been fixed in the form of tri-calcium phosphate or carbonato-phosphate. These forms would be redissolved in the acid extracting solution used for the determination of available phosphate.

There appears to be no difference in the amount or rate of phosphorus fixation due to differences in fertilizer treatments used on these soils.

Greenhouse Study

The data for available phosphorus determinations on greenhouse incubated soils is not given as these data were almost exactly the same as those in Table 2. The amount of phosphorus fixation in the greenhouse incubated soils was, on the average, very slightly less than occurred in the laboratory incubation. For example, Oxbow soil incubated in the laboratory for 24 weeks with 11–48–0 had 79.6 p.p.m. available phosphorus while after similar incubation in the greenhouse it had 82.0 p.p.m. available phosphorus. This may have been due to the maintenance of more uniform and optimum conditions of soil moisture during the greenhouse incubation. Furthermore, micro-biological activity was probably greater in the greenhouse incubated soils and this may have released phosphorus from organic compounds or have reduced fixation. Copeland and Merkle (2) have shown that lower phosphorus fixation occurs in the presence of actively decomposing organic matter.

The data for nitrate accumulation in the greenhouse incubated soils are given in Table 3. These results are introduced at this point so that their possible effect on crop growth may be pointed out. The Lloydminster soil shows the least nitrate accumulation for all treatments, while the Yorkton and Oxbow soils show about the same accumulation of nitrates. The greatest accumulation of nitrate in all cases occurs with the 16–20–0 treatment. The 11–48–0 treatment also shows a marked increase in nitrate over the check and has a larger percentage of applied ammonia converted to nitrate than is shown by the 16–20–0. However, as shown by Table 3, the 16–20–0 treatment had a considerably higher content of ammonia so that with it the actual amount converted to nitrate nitrogen was the highest of any treatment.

TABLE 3.—EFFECT OF FERTILIZER TREATMENT AND SUBSEQUENT PERIOD OF INCUBATION ON NITRATE ACCUMULATION IN THE THREE SOILS USED FOR POT EXPERIMENTS

(Results in p.p.m. of nitrate nitrogen)

Soil	Treatment	Incubation period				
		0 weeks	3 weeks	6 weeks	9 weeks	% NH_4 converted‡
Lloydminster	Check*	16.7	26.5	33.3	33.3	—
	11–48–0	16.0	39.5	44.0	44.2	41.6
	16–20–0	15.3	65.0	67.4	70.0	28.7
	T. S. P.	15.7	27.3	29.5	32.1	—
	P–NO_3	28.5	34.2	50.5	46.2	—
Oxbow	Check	57.5	72.0	78.4	70.6	—
	11–48–0	59.1	72.0	95.0	83.4	48.8
	16–20–0	57.0	119.3	110.3	111.1	43.6
	T. S. P.	57.4	67.7	75.1	67.3	—
	P–NO_3	70.8	88.3	85.0	74.9	—
Yorkton	Check	38.2	64.0	68.1	69.4	—
	11–48–0	38.1	53.4	79.7	85.3	56.8
	16–20–0	38.4	115.0	116.6	116.6	50.8
	T. S. P.	39.1	57.0	67.8	67.9	—
	P–NO_3	51.8	70.1	73.4	82.0	—

* NOTE: The amount of ammoniacal nitrogen in p.p.m. contained in the various fertilizer treatments was as follows: check—nil; 11–48–0, 26.2; 16–20–0, 93.0; T. S. P., nil; and P–NO_3, 13.1.

‡ The figures for % ammoniacal nitrogen converted indicate the % of applied ammoniacal nitrogen which has been converted to nitrate nitrogen during the 9 weeks' incubation period and are based on the assumption that nitrate formed from other sources was equal to the check.

For the three soils, the rate of nitrate accumulation is slightly lower on the 0–38–0 treatment than on the check. This may be explained by the greater activity of micro-organisms in the presence of sufficient phosphorus. The increased micro-organism population probably utilizes part of the nitrate in forming its own body tissues. All soils, especially those containing added ammonium carrying fertilizer, show a rapid increase in nitrate content during the first three weeks of incubation with a slower rate of accumulation thereafter. However, the maximum nitrate accumulation is reached on the Oxbow soil within six weeks followed by a decline. This occurs in all treatments on this soil including the check. Hedlin (7) obtained somewhat similar results, showing a decrease in nitrate accumulation after four or six weeks' incubation for a number of samples from the Weyburn Association. This decline is unusual and can perhaps be accounted for by the increased activity of micro-organism which accompanies incubation resulting in utilization of accumulated nitrates.

The data contained in Table 4 show the effect of fertilizer treatment and subsequent period of incubation on yield of barley grown for seven weeks on each of three soils. At the bottom of the table the necessary differences in yield required for statistical significance are given.

On the Lloydminster soil significant increases are obtained for all fertilizer treatments. The yield with 16–20–0 is especially high as is to be expected from the use under greenhouse conditions of a fertilizer high in nitrogen. The large response to 11–48–0 and 0–38–0 is, however, a good indication of the need for phosphate fertilizer in this soil.

Table 4 shows a significant decrease in yield as a result of three weeks' incubation for the fertilized treatments of the Lloydminster soil. Further decreases occur in the case of the 16–20–0 treatment and 0–38–0 with NH_4NO_3 treatment but they are slight compared to the original decrease for 3 weeks' incubation. Since no decrease in yield occurs as a result of

TABLE 4.—EFFECT OF FERTILIZER TREATMENT AND SUBSEQUENT PERIOD OF INCUBATION ON YIELD OF BARLEY GROWN FOR SEVEN WEEKS ON THREE DIFFERENT SOILS

(Mean values of four replicates in grams)

Soil	Treatment	Incubation period			
		0 weeks	3 weeks	6 weeks	9 weeks
Lloydminster	Check	5.48	5.43	5.24	5.34
	11–48–0	6.36	5.78	5.86	5.80
	16–20–0	7.22	6.74	6.55	6.60
	T. S. P.	5.88	5.63	5.66	5.53
	P–NO_3	6.91	6.59	6.50	6.37
Oxbow	Check	5.56	5.52	5.44	5.39
	11–48–0	5.94	5.77	5.90	5.91
	16–20–0	6.68	6.53	6.57	6.52
	T. S. P.	5.89	5.65	5.54	5.48
	P–NO_3	6.30	5.89	5.71	5.71
Yorkton	Check	6.02	6.23	6.55	6.54
	11–48–0	6.26	6.25	6.56	6.89
	16–20–0	6.71	7.24	7.36	7.52
	T. S. P.	6.22	6.26	6.64	6.78
	P–NO_3	6.46	6.84	7.16	7.40

Necessary difference in grams for significance at		*5% point*	*1% point*
Lloydminster	between treatments	.13	.17
	between periods	.11	.14
Oxbow	between treatments	.11	.15
	between periods	.10	.13
Yorkton	between treatments	.20	.27
	between periods	.17	.23

incubating the check treatment for 3 weeks, the decrease in yield, due to the same incubation of the fertilized soil, must be attributed to phosphorus fixation during the period of incubation.

The data show that the Oxbow soil responds to phosphate fertilizer, although the increases in yield are not as great as with the Lloydminster soil. There is a significant decrease in yield due to three weeks' incubation of all fertilized treatments. This decrease is attributed to phosphorus fixation which occurred during the incubation period. This conclusion is supported by results obtained from chemical analysis which shows a decrease in available phosphorus as a result of incubation.

Under the conditions of this experiment, barley on the Yorkton soil responds considerably less to applied fertilizers than it does on either the Lloydminster or Oxbow soils. The Yorkton check also has a much higher yield than the Lloydminster or Oxbow check. This is to be expected from the chemical analysis which shows the Yorkton soil to have a higher content of available phosphorus than either the Oxbow or Lloydminster soils. However, there is some response to added phosphate on the Yorkton

soil. In all treatments including the check, there is a significant increase in yield due to incubation. In some treatments this occurs as a result of three weeks' incubation, in other cases increases are shown as a result of six or nine week incubation periods. This is quite different from what occurred on the Lloydminster soil. If any phosphorus was fixed in the Yorkton soil during the incubation period then there were enough compensating factors to completely offset this effect. Part of the increase in yield may be attributed to nitrate accumulation during incubation. However, increased nitrate content occurred in the other incubated soils and still decreases in yield were observed. Another possible explanation is that offered by McGeorge *et al.* (11). They have shown that the solubility of phosphorus in calcareous soils above pH 7.6 can be increased by such incubation. This increase in phosphorus solubility is due to the action of CO_2 formed during the period of incubation as a result of micro-biological activity. The increased solubility of phosphate may have been an important factor in producing the increased yields which occurred on this soil as a result of incubation.

With the Yorkton and Lloydminster soils the triple superphosphate plus ammonium nitrate treatment consistently and significantly out-yields the ammonium phosphate 11–48–0 treatment which provides the same amount of nitrogen and phosphorus. This difference would seem to be due either to the nitrate content of the first treatment or to the difference in the chemical form of the phosphate contained in the two fertilizers. The data of Table 3 seem to discount the suggestion that these yield differences are due to differences in nitrate content of the soils. Therefore weight is added to the suggestion that the differences in yield are due to differences in the chemical form of the phosphorus contained in the two treatments. This is an important consideration and requires further investigation.

The need for added phosphorus in the soils used for this work is not only reflected in the yield but also in the composition of the plants. The results of some phosphorus determinations on the plants grown on the various fertilized and incubated soils are given in Table 5. The most

TABLE 5.—EFFECT OF FERTILIZATION AND SUBSEQUENT INCUBATION ON THE PERCENTAGE PHOSPHORUS IN PLANT MATERIAL

(Mean values of four replicates in per cent.)

Soil	Treatment	Soil Incubation Period			
		0 weeks	3 weeks	6 weeks	9 weeks
Lloydminster	Check	.263	.253	.261	.252
	11–48–0	.471	.518	.426	.474
	16–20–0	.449	.394	.402	.381
	T. S. P.	.510	.400	.488	.417
	P–NO_3	.454	.378	.456	.436
Oxbow	Check	.256	.258	.264	.301
	11–48–0	.571	.535	.555	.531
Yorkton	Check	.261	.247	.258	.242
	11–48–0	.467	.462	.486	.442

notable observation is the high phosphorus content of the plants grown on fertilized soil as compared to the check. This would have special significance where the crops grown are to be used on the farm for feeding live stock. Some of the increase in phosphorus content due to fertilization may represent luxury consumption by the plant. However, the large increase obtained would seem to indicate that the plants growing on unfertilized soil are in continuous need of additional phosphorus. A somewhat higher phosphorus content is found in the plants grown on fertilized Oxbow soil than on the other soils similarly treated. The more nearly optimum pH of the Oxbow soil for maximum absorption of phosphorus by the plant may account for this difference. No significant difference was found due to incubation of any of the treatments.

The acidic Lloydminster soil fixes applied phosphate to the greatest extent, the Oxbow soil fixes considerably less and the Yorkton soil fixes none as measured by the modified Truog solution used. The podzolic Loon River soil fixes more phosphorus than would be expected from its high pH, high $SiO_2 : R_2O_3$ ratio and low phosphorus fixing capacity. This may be attributed to its low organic matter content.

The importance of organic matter in minimizing phosphorus fixation in soils below pH 7 has been shown by Dunn (4). Addition of organic matter in conjunction with lime should reduce the fixing ability of the Loon River soil considerably. The increase in base exchange capacity and the saturation of the exchange complex with calcium or magnesium has been shown by Heck (6) to be of considerable importance in decreasing the amount of phosphorus fixed by a soil. This should be especially applicable to a highly leached soil such as the Loon River.

As indicated from the data contained in Table 1, Heck's (5) rapid laboratory determination of phosphorus fixing capacity is of doubtful value for Saskatchewan soils. The results obtained from the Lloydminster and Oxbow soils show the same relationship between phosphorus fixing capacity and phosphorus fixed under these experimental conditions. However the Loon River soil has a very low phosphorus fixing capacity yet fixes a large amount of phosphorus. The determination of the phosphorus fixing capacity of the Yorkton soil is likewise of little value. It appears that various factors are involved in phosphorus fixation in the field that cannot be duplicated in a rapid laboratory test. However the laboratory test may have considerable value when sufficient data are available to relate the results obtained to field results.

It is known that phosphorus requirements of annual plants are relatively heavy during the first few weeks after germination and again near the end of their life cycle while fruits and seeds are maturing. Under the conditions of the experiments reported here phosphate fixation was largely complete after three weeks of incubation. If the granulated phosphate fertilizers now commonly used are fixed with similar rapidity under field conditions, then fertilized cereal crops may lack available phosphorus in their final stages of growth. Should this be verified it would be desirable to try and develop phosphate fertilizers or fertilizing techniques which would insure the presence of adequate amounts of available phosphorus at the time crops are maturing.

SUMMARY

The rate and extent of phosphorus fixation were studied using various phosphatic fertilizers on four Saskatchewan soils varying markedly in reaction. Incubation experiments and greenhouse methods were used in conducting the study. The results may be summarized as follows:

1. By means of laboratory incubation work, using an application of phosphate fertilizers equivalent to 50 p.p.m. of elemental phosphorus, it was shown that the Lloydminster soil fixed 30% of the applied phosphorus while the Loon River and Oxbow soils fixed 26 and 20% respectively. The Yorkton soil showed no phosphorus fixation according to the method used. These results are broadly substantiated by results obtained from greenhouse experiments.

2. The type of phosphate fertilizer used or the nitrogen carried by the fertilizer did not influence the rate of phosphorus fixation as determined by the analytical method used. However, with the Yorkton and Lloydminster soils two fertilizer treatments supplying the same amounts of nitrogen and phosphorus, but in different forms, had consistent and significant yield differences when barley was grown. These yield differences may be a result of the difference in the chemical form of the phosphate used.

3. The reaction of the black zone soils was found to be the most important factor affecting phosphorus fixation, the greatest amount of fixation occurring in the most acid soils.

4. The high fixation found in the podzolic Loon River soil is attributed to its low organic matter content.

5. Maximum fixation occurred during the first three weeks of incubation.

6. Yield on calcareous Yorkton soil increased as a result of incubation. This is probably due to the accumulation of nitrates and to CO_2 production.

7. Plants grown on fertilized soil had a much higher phosphate content than those grown on the check.

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